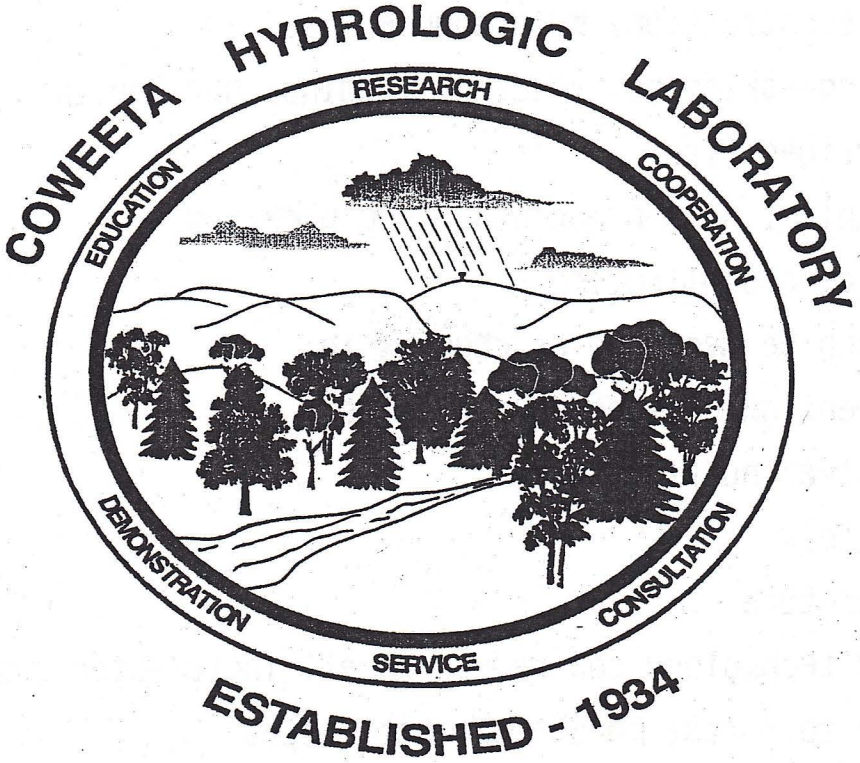
IMPACT OF FOREST MANAGEMENT ON WATER QUALITY OF MOUNTAIN STREAMS



SUMMARY OF RESEARCH RESULTS FROM:

COWEETA HYDROLOGIC LABORATORY
SOUTHERN RESEARCH STATION
FOREST SERVICE, USDA
3160 COWEETA LAB ROAD
OTTO NC 28763

WATER QUALITY STUDIES AT COWEETA HYDROLOGIC LABORATORY

Activities which can impact water quality:

- Road construction, maintenance, use
- Logging--skidding, yarding, loading, and hauling
- Prescribed fire
- Mechanical site preparation and planting
- Pesticide application

Water quality can be measured as changes in:

- Sediment and suspended particles
- Dissolved nutrients
- Chemicals
- Temperature

Methodology and technology can reduce or eliminate water quality damage due to forest management activities.

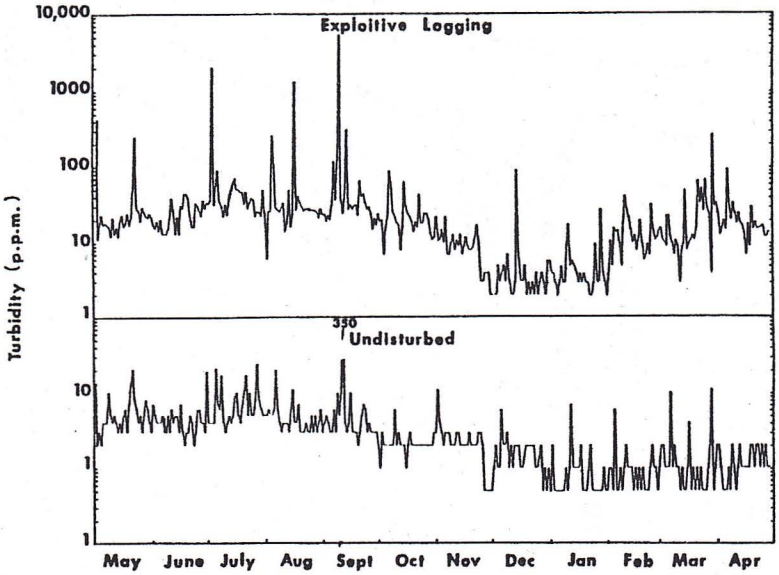
- Road construction has the greatest potential for damage
- Land clearing and planting by heavy machinery have high potential for damage on Piedmont lands.
- Forest cutting can alter water temperature and chemistry but does not cause erosion
- Methods of removing logs from the woods vary greatly in their potential for causing erosion
- Prescribed fire has minimal impact on water quality
- Pellatized herbicides allow little to no leakage of active materials into streams.

BRIEF HISTORY OF FOREST ROAD STUDIES AT

COWEETA HYDROLOGIC LABORATORY

Woods roads were identified as major causes of reduced water quality by the 1940's.

Exploitive logging demonstration (Watershed 10) with abusive skidding and streamside roads produced large soil losses, 1946-48.



Limited impact contour roads and uphill skidding demonstrated (Watersheds 40 and 41), 1955-56.

Testing of new road designs for **economic viability** in sales on two Ranger Districts (Stamp Creek, Georgia, and Blacks Run, Virginia), 1956-57.

Improved road design used in **multiresource management** demonstration (Watershed 28), 1962-63.

Adoption of road design by National Forest System and by forest industries.

Testing of **operational application** of road design (Watershed 7), 1976-78.

Verification of **filter-strip** guidelines, 1982-84.

Participation in national Water Erosion Prediction Project (WEPP), 1987+ and implementation of GIS-based **erosion prediction model**, 1993+.

Facilitate application of road **BMP's** through State, FS R-8, EPA R-4 teams and National Training Center course, 1989+.

N
10
40
41

CULVERT SIZE (CMP) FOR TEMPORARY ROADS

Pipe Capacity[1] c.f.s.	log(c.f.s.)	Minimum Pipe Diameter (inches)
2.1	.32	12
3.7	.57	15
5.8	.76	18
8.6	.93	21
12.0	1.08	24
20.9	1.32	30
32.9	1.52	36
48.4	1.68	42
67.5	1.83	48
90.6	1.96	54

To Estimate Mean Yearly[2] Peak Flow:

Mountain Lands, Forested[3]

$$\log(\text{c.f.s.}) = -11.580 + 0.803 \log(\text{Area, acres}) + 3.038 \log(\text{Top Elevation, feet}) + 0.079 \text{ (if logged)}$$

Mountain and Piedmont, Mixed Cover[4]

$$\log(\text{c.f.s.}) = 0.143 + 0.706 \log(\text{Area, acres})$$

Coastal Plain, Mixed Cover[4]

$$\log(\text{c.f.s.}) = 0.090 + 0.664 \log(\text{Area, acres})$$

[1] Flow in cubic feet per second is given for full pipe. If water depth is twice pipe diameter, flow capacity is approximately doubled. Flow capacity is slightly higher for installations with headwalls.

[2] See cited references for equations for longer recurrence intervals.

[3] Douglass, J. E. 1974. Flood frequencies and bridge and culvert sizes for forested mountains of North Carolina. USDA Forest Service General Technical Report SE-4.

[4] Jackson, N. M., Jr. 1976. Magnitude and frequency of floods in North Carolina. U.S. Geological Survey Water Resources Investigations 76-17.

Table 1.—*A summary of specifications for truck and tractor skid trails into a mountain watershed. These trails are in addition to forest roads, whose construction is governed by existing standards*

Specifications	Climbing truck trails	Contour truck trails[1]	Tractor skid trails
Route layout	Forest Officer	Forest Officer	Operator subject to approval
Stream crossings	Avoid	At right angles on dipping grades with culverts	Not permitted
Grades	13 percent maximum	Least practical	None specified
Right-of-way	Clear 24 feet	Same	Least possible
Slash disposal	Pile at toe of fill slope	Same	Lay back in trail
Backslopes	Leave vertical	Same	Not permitted
Curves	Not less than 25-foot radius	Same	No limit
Cut and fill	Wheel track on cut soil	Least practical	Not permitted
Broad based dips	Spacing (m) = 100 m - 6.4(slope percent)	Take advantage of local terrain	Not permitted
Outsloping	3 percent	Same	Not permitted
Surface	Coarse gravel on steep pitches (dips)	Shoulders grassed	Keep dozer blade out of soil
Inside ditching	Usually none	Only at stream crossings	Not permitted
Traffic control	Gated during bad weather	Same	Only by foot after logging
Maintenance[2]	Inspect annually; repair dips; fertilize as needed	Inspect culverts annually; fertilize as needed	None required

[1]Temporary contour truck trails constructed just as permanent contour truck trails but "put to bed" at completion of logging.

[2]At end of logging, all permanent truck trail surfaces should be dressed, fertilized, and seeded.

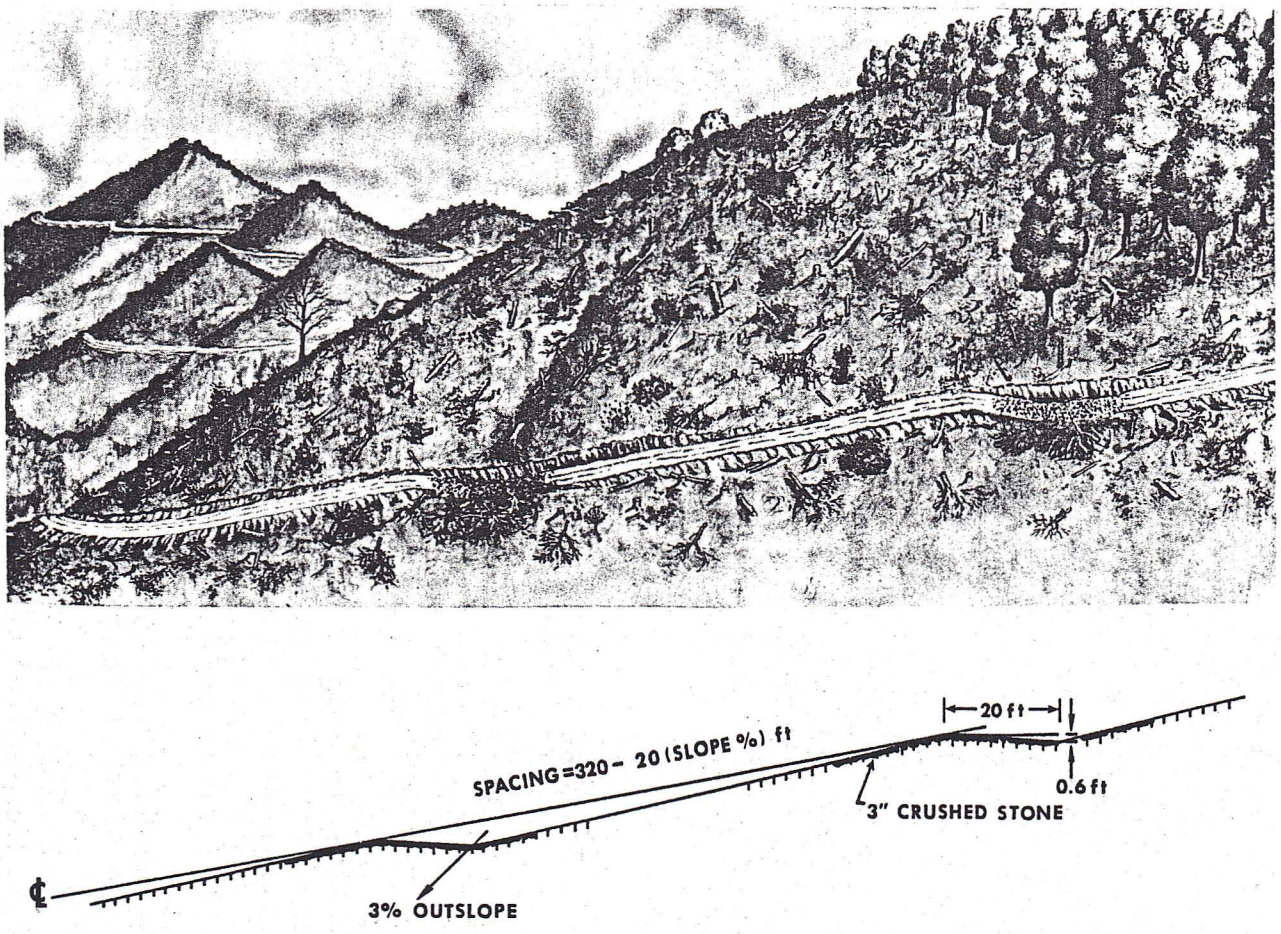
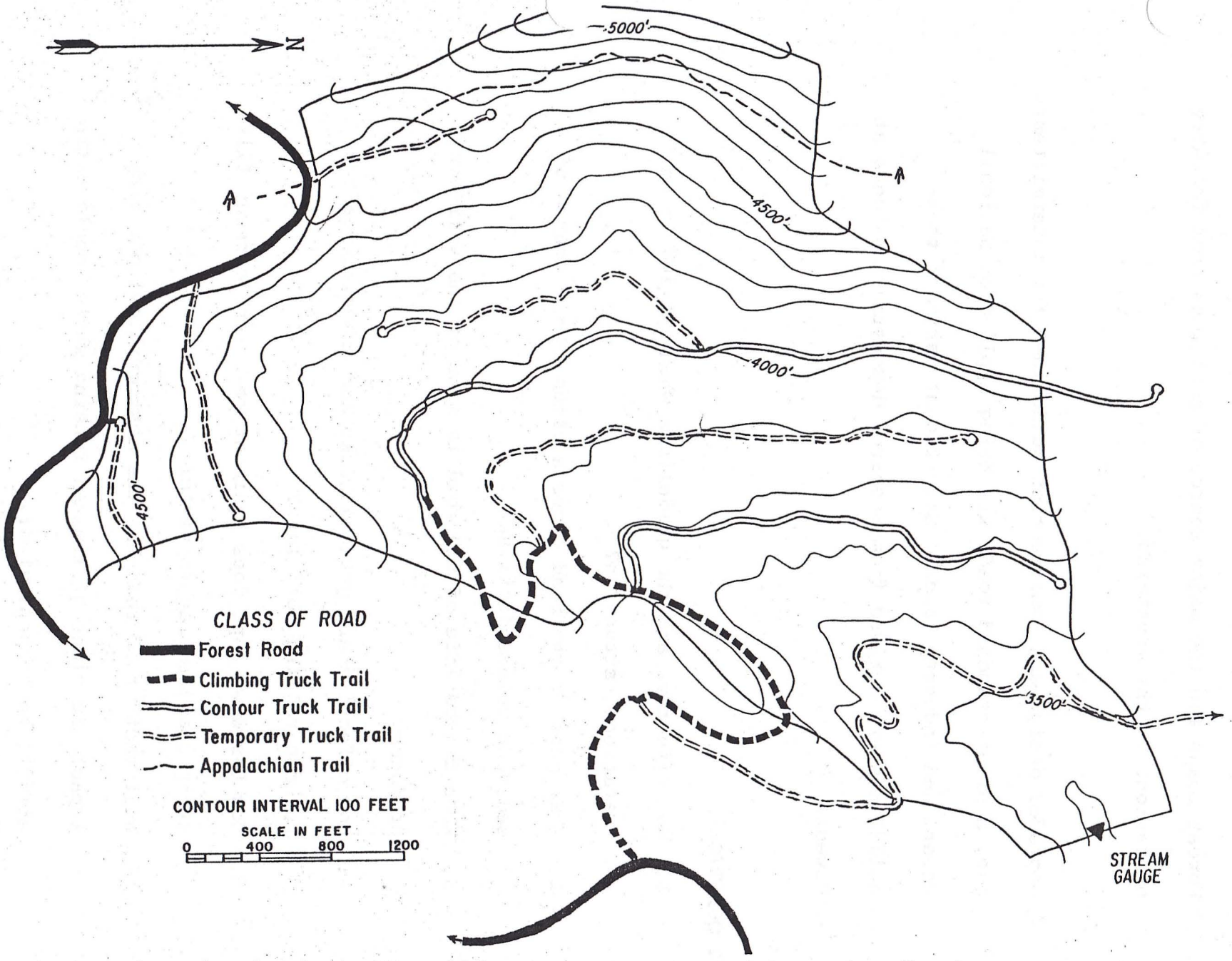


Figure 4.—*Broad-based dips turn the water out of forest roads. A key feature of the truck trail system, they are designed to require almost no maintenance.*



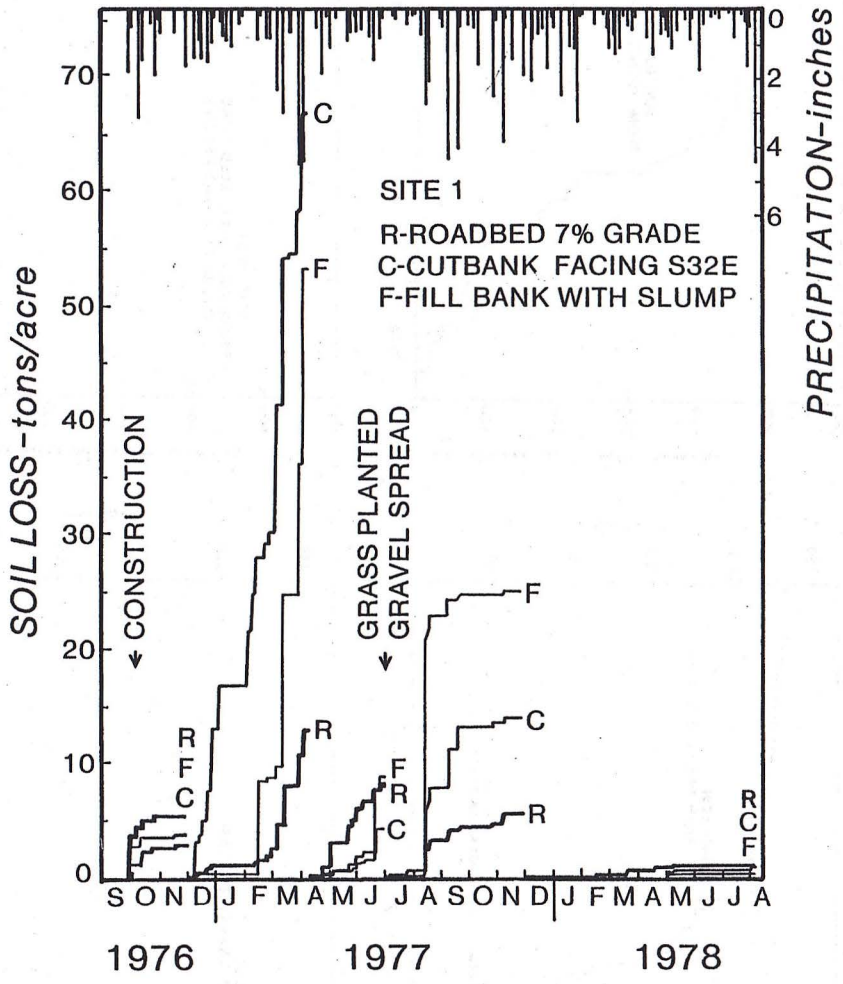
—Access is a key feature of multiple resource management. The truck trail system constructed during this study recognized the need for continuing, essentially maintenance-free access for all potential uses and protection needs—a road system which will never need relocation or reconstruction.

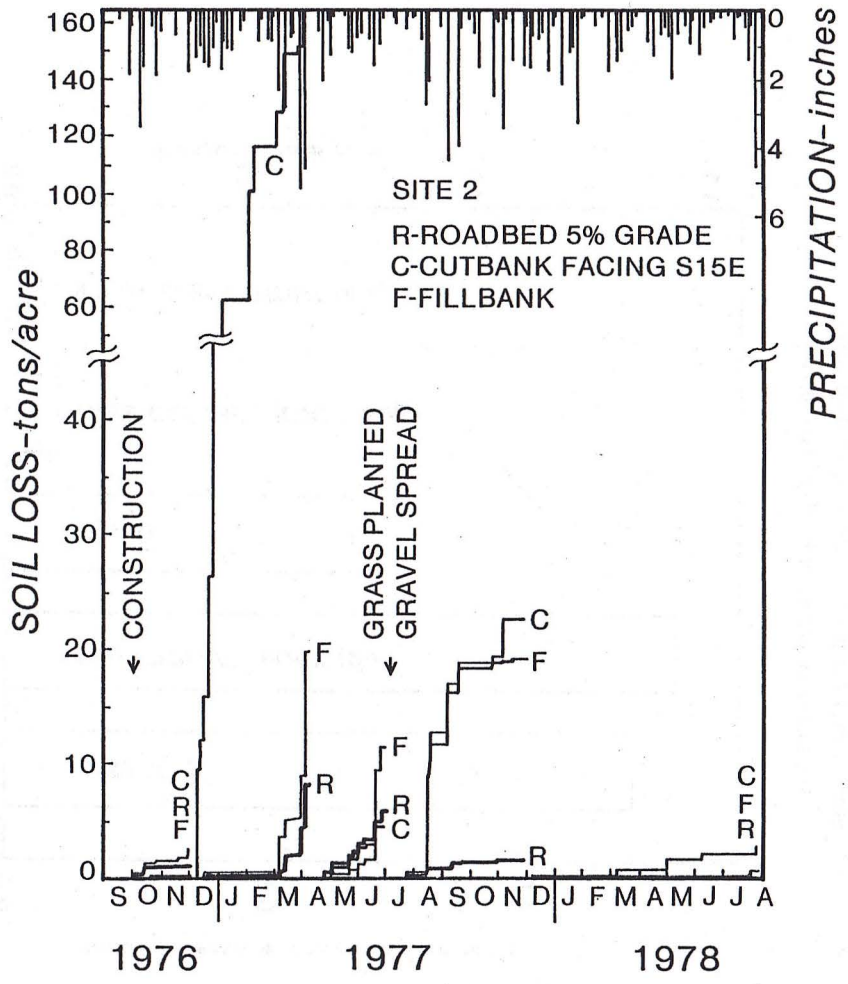
PROBLEM: Forest roads are the major source of soil loss from forestry operations in the mountains.

STATUS: Upgraded design and construction guidelines for intermittent-use, minimum standard roads are being applied on National Forest and industry lands. Significant parts of these guidelines are derived from research demonstrations done at Coweeta.

RESEARCH QUESTIONS:

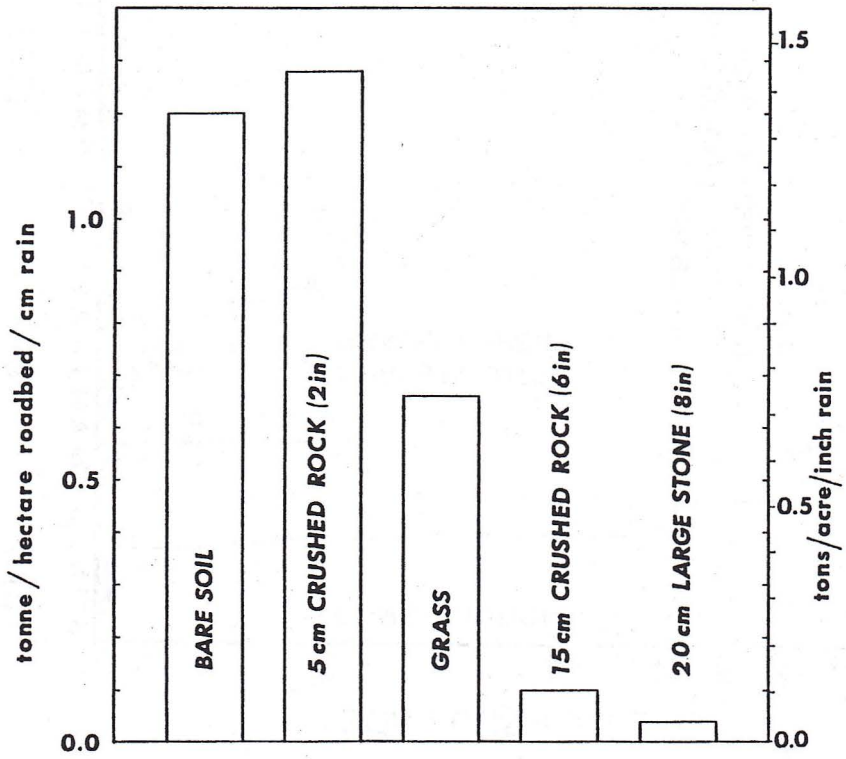
1. How effective are the guidelines when applied in an operational situation?
2. What part of the road cross section is the source of sediment released off site?
3. When in the life of the road is most of the sediment produced?
4. How effective are grassed banks and graveled roadbeds for controlling soil loss?
5. How far downslope does sediment move--are current filter strip standards appropriate?
6. What section of road has the most critical off site impact--in times of limited funding where should extra efforts be concentrated?

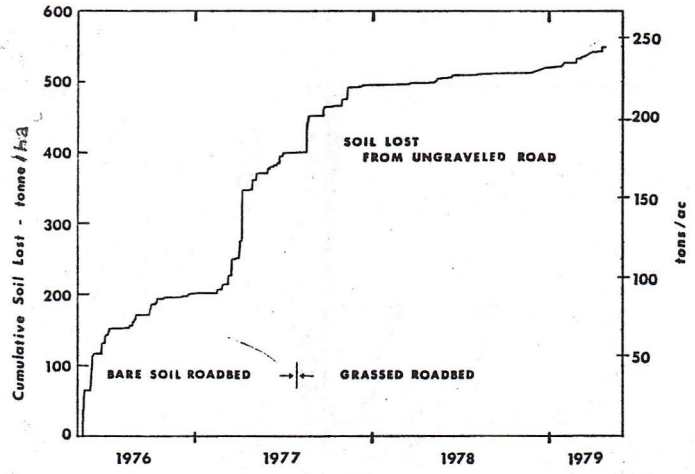

SOIL LOSS-tons/acre
PRECIPITATION-inches
SITE 1
R-ROADBED 7% GRADE
C-CUTBANK FACING S32E
F-FILL BANK WITH SLUMP
CONSTRUCTION
GRASS PLANTED
GRAVEL SPREAD
0
10
20
30
40
50
60
70
0
2
4
6
S O N D J F M A M J J A S O N D J F M A M J J A
1976
1977
1978

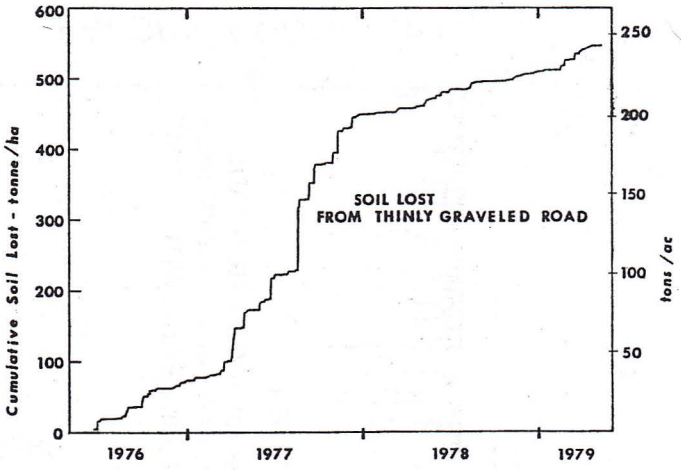

SOIL LOSS-tons/acre
PRECIPITATION-inches
SITE 2
R-ROADBED 5% GRADE
C-CUTBANK FACING S15E
F-FILLBANK
CONSTRUCTION
GRASS PLANTED
GRAVEL SPREAD
0
10
20
30
40
60
80
100
120
140
160
0
2
4
6
S O N D J F M A M J J A S O N D J F M A M J J A
1976
1977
1978

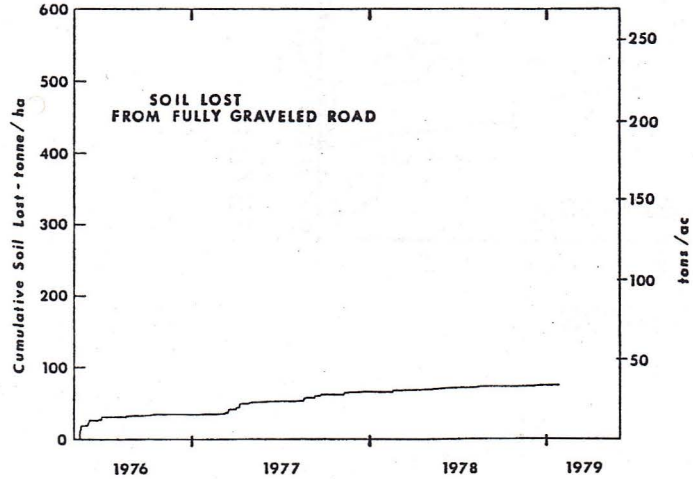
COMPARISON OF ROAD SURFACING MATERIALS

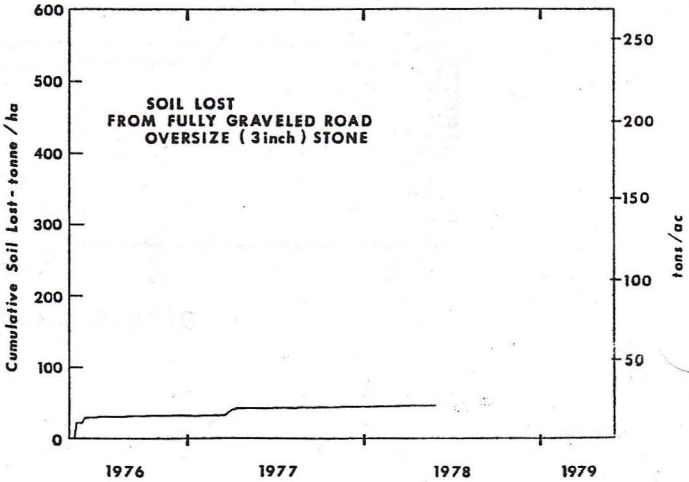
Two inches of gravel did not prevent soil loss,
Grassed road bed had half the loss of bare soil,
Six inches of gravel controlled soil loss.

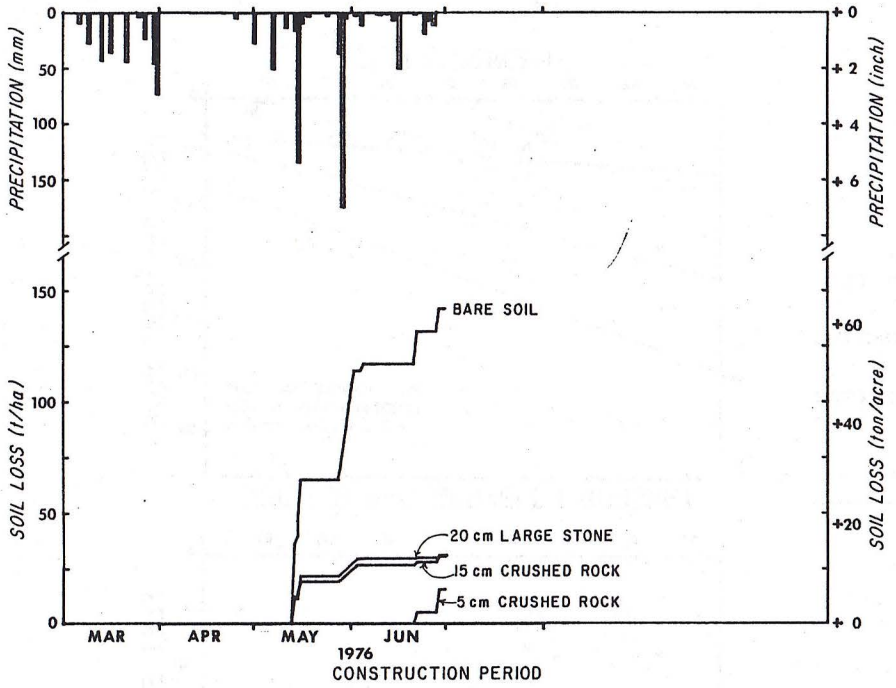


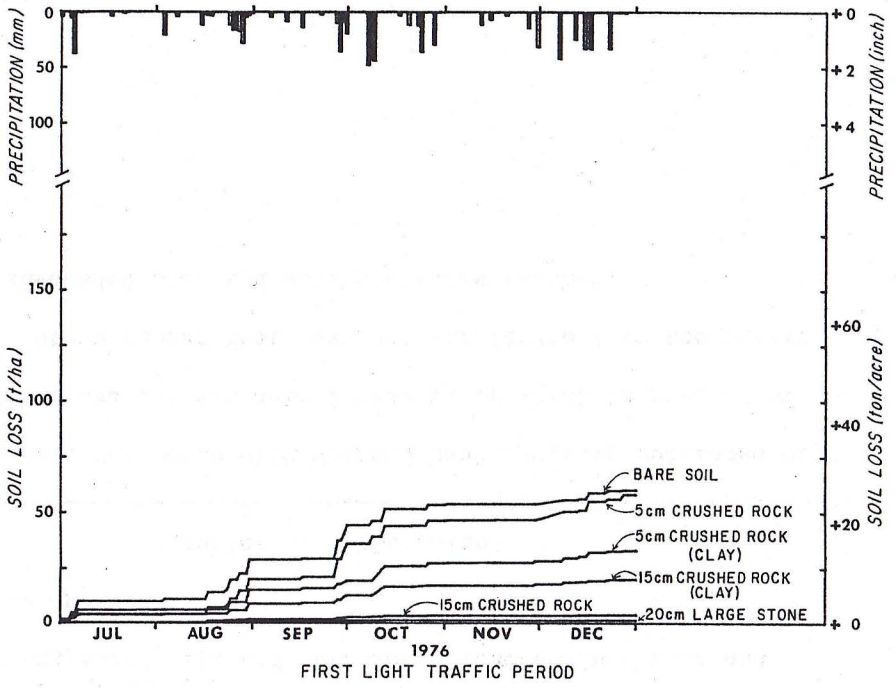


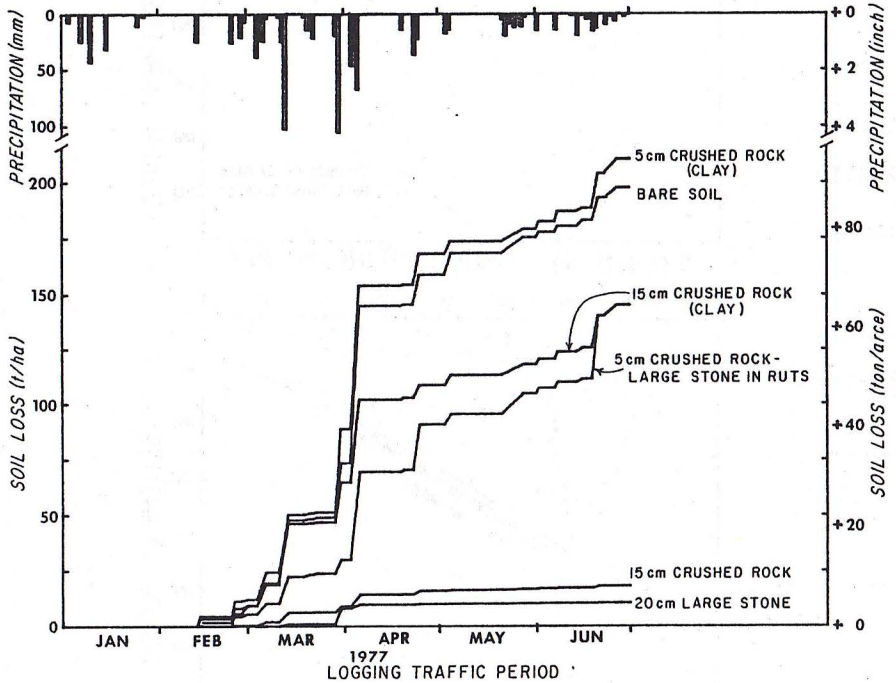


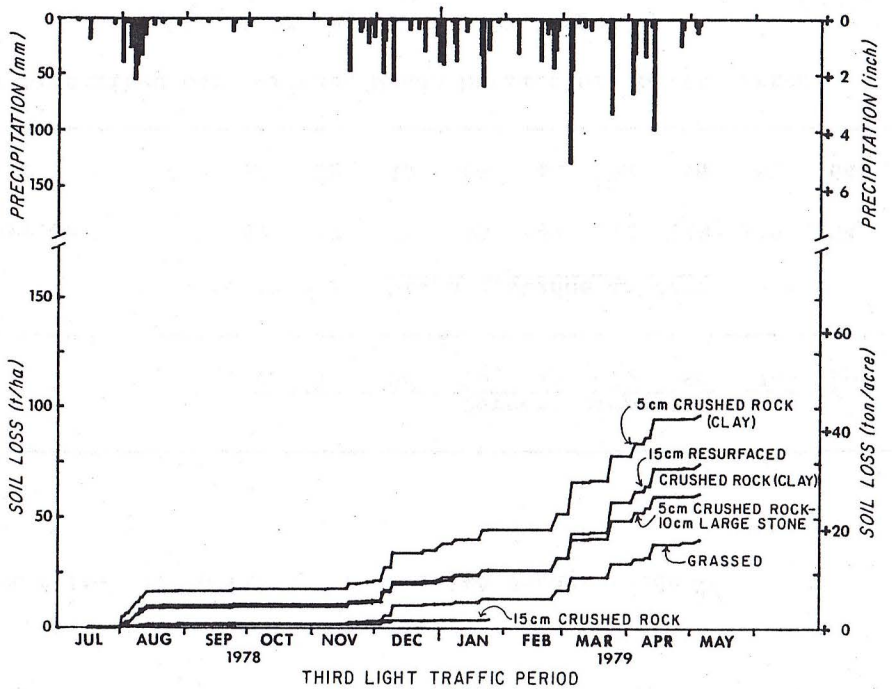


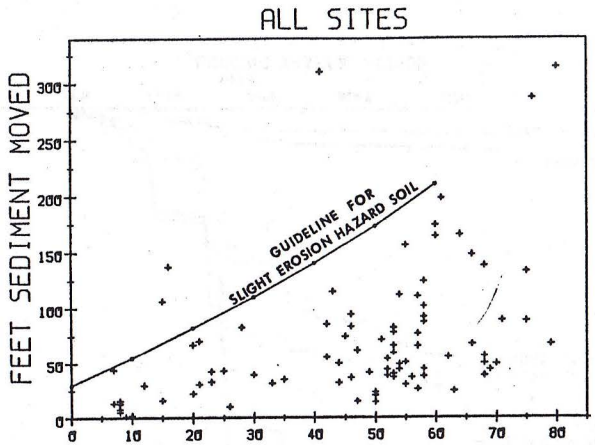


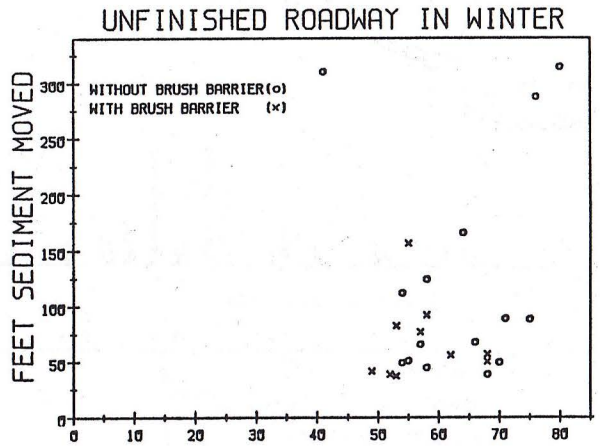

PRECIPITATION (mm)
PRECIPITATION (inch)
SOIL LOSS (t/ha)
SOIL LOSS (ton/acre)
BARE SOIL
20 cm LARGE STONE
15 cm CRUSHED ROCK
5 cm CRUSHED ROCK
MAR
APR
MAY
JUN
1976
CONSTRUCTION PERIOD

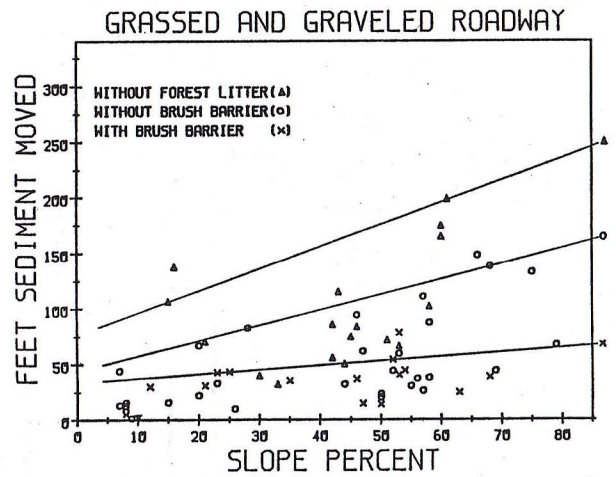

PRECIPITATION (mm)
PRECIPITATION (inch)
SOIL LOSS (t/ha)
SOIL LOSS (ton/acre)
BARE SOIL
5cm CRUSHED ROCK
5cm CRUSHED ROCK (CLAY)
15cm CRUSHED ROCK (CLAY)
15cm CRUSHED ROCK
20cm LARGE STONE
JUL
AUG
SEP
OCT
NOV
DEC
1976
FIRST LIGHT TRAFFIC PERIOD


PRECIPITATION (mm)
PRECIPITATION (inch)
SOIL LOSS (t/ha)
SOIL LOSS (ton/acre)
5cm CRUSHED ROCK (CLAY)
BARE SOIL
15cm CRUSHED ROCK (CLAY)
5cm CRUSHED ROCK-LARGE STONE IN RUTS
15 cm CRUSHED ROCK
20cm LARGE STONE
JAN
FEB
MAR
APR
MAY
JUN
1977
LOGGING TRAFFIC PERIOD


PRECIPITATION (mm)
PRECIPITATION (inch)
SOIL LOSS (t/ha)
SOIL LOSS (ton/acre)
5cm CRUSHED ROCK (CLAY)
15cm RESURFACED CRUSHED ROCK (CLAY)
5cm CRUSHED ROCK-10cm LARGE STONE
GRASSED
15cm CRUSHED ROCK
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
1978
1979
THIRD LIGHT TRAFFIC PERIOD







Minimum filter strip width for graveled forest roads.[1/]

Filter strip	Percent slope 0	10	20	30	40	50	60	70	80
	- - - - Slope distance in feet - - - -								
Without brush barrier	43	57	71	85	99	112	126	140	154
With brush barrier	32	36	40	44	48	52	56	60	64

For prescribed burn without brush barrier or forest litter:

Add 31 ft. + 6.4 ft./10% slope.

For ungrassed fill and unfinished roadbed in winter and early spring:

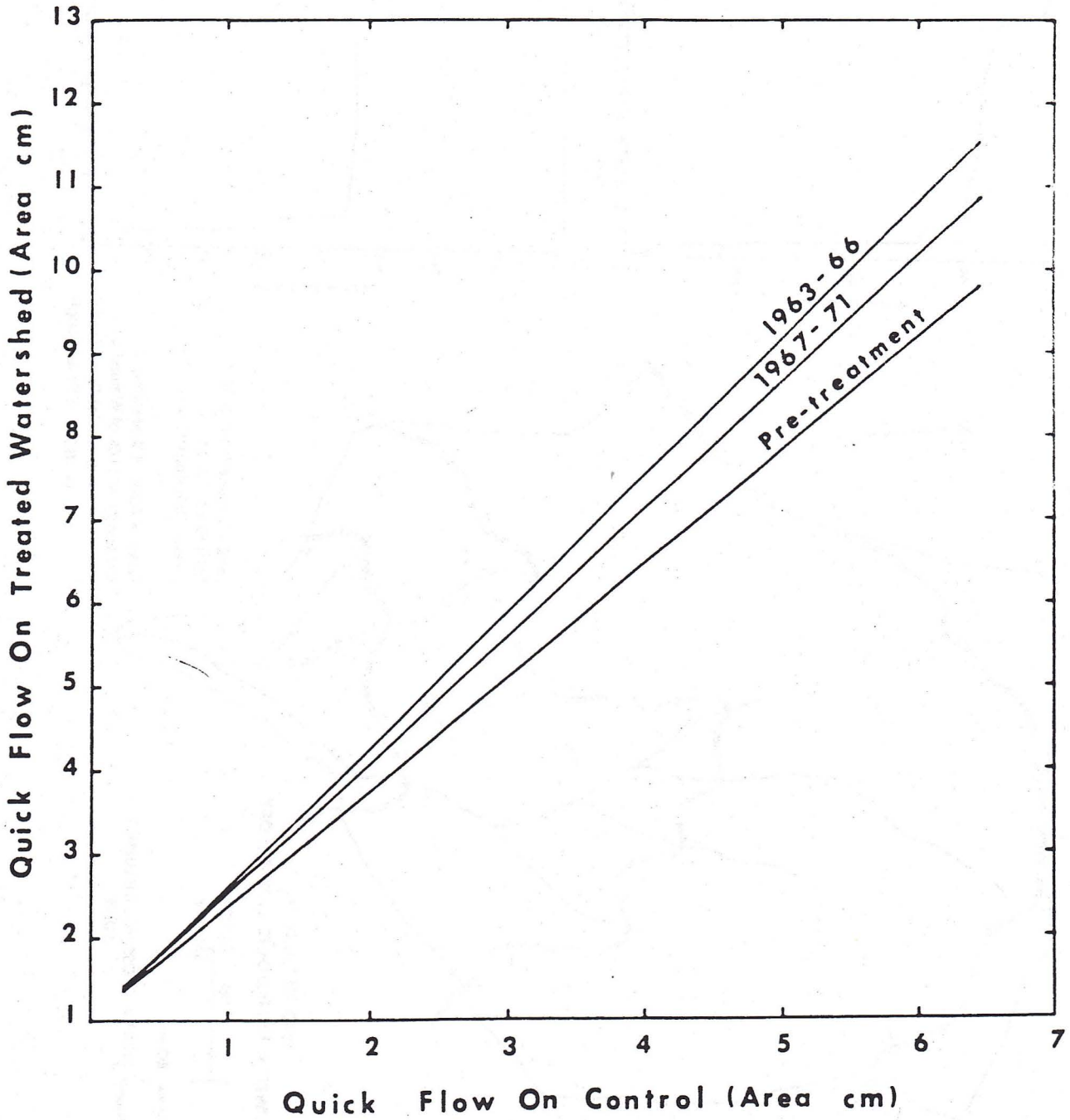
Double the table values.

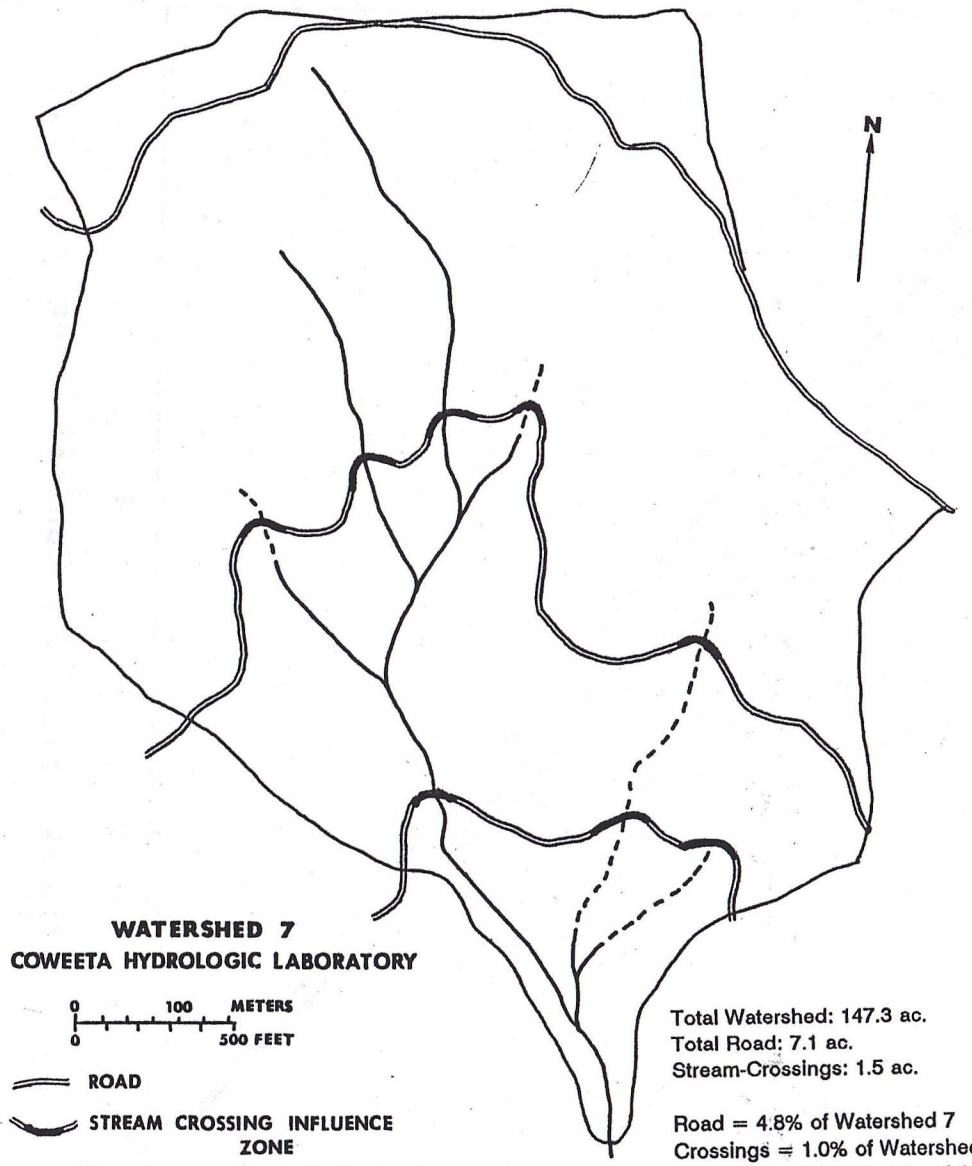
[1/] Distances are for roads with grassed banks, either outsloped or drained by ditchline and culvert onto forest floor which is covered by hardwood litter. Storm runoff that does not infiltrate into the forest soil will carry suspended clay and silt particles farther.

12

CAREFUL ROAD BUILDING AND LOGGING DO NOT CAUSE FLOODS.

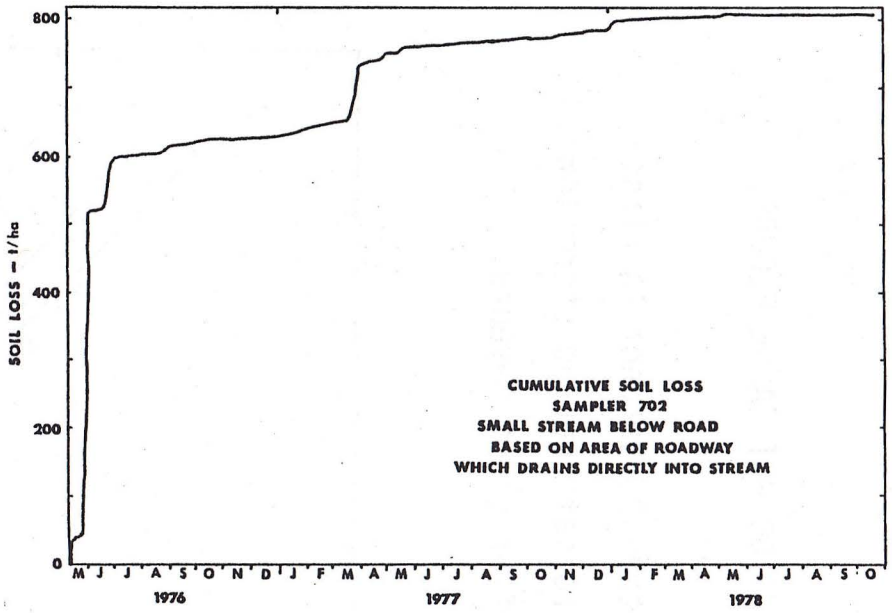
Stormflows were increased less than 20 percent in first years after cutting. Regrowing forest reduced stormflows below pretreatment levels after about 8-years.

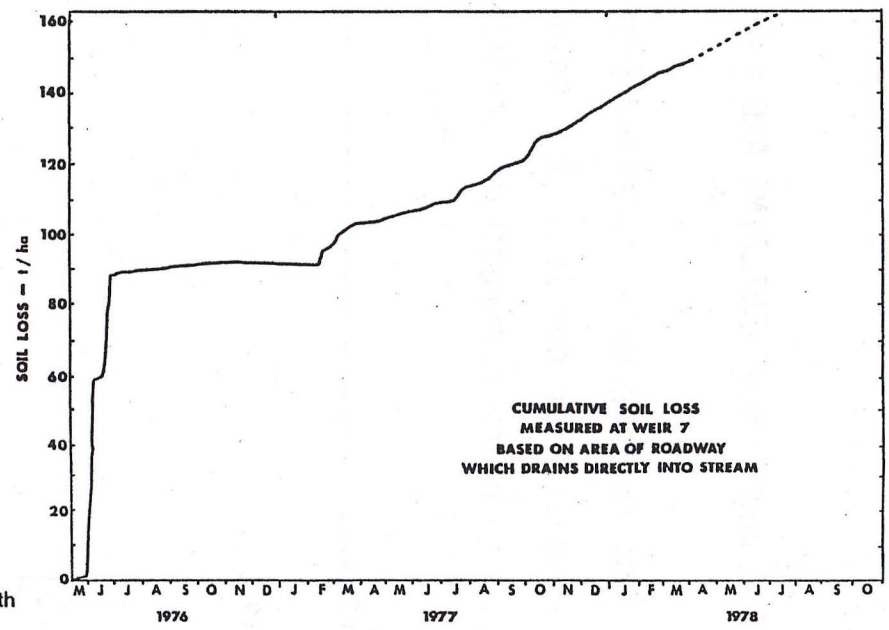


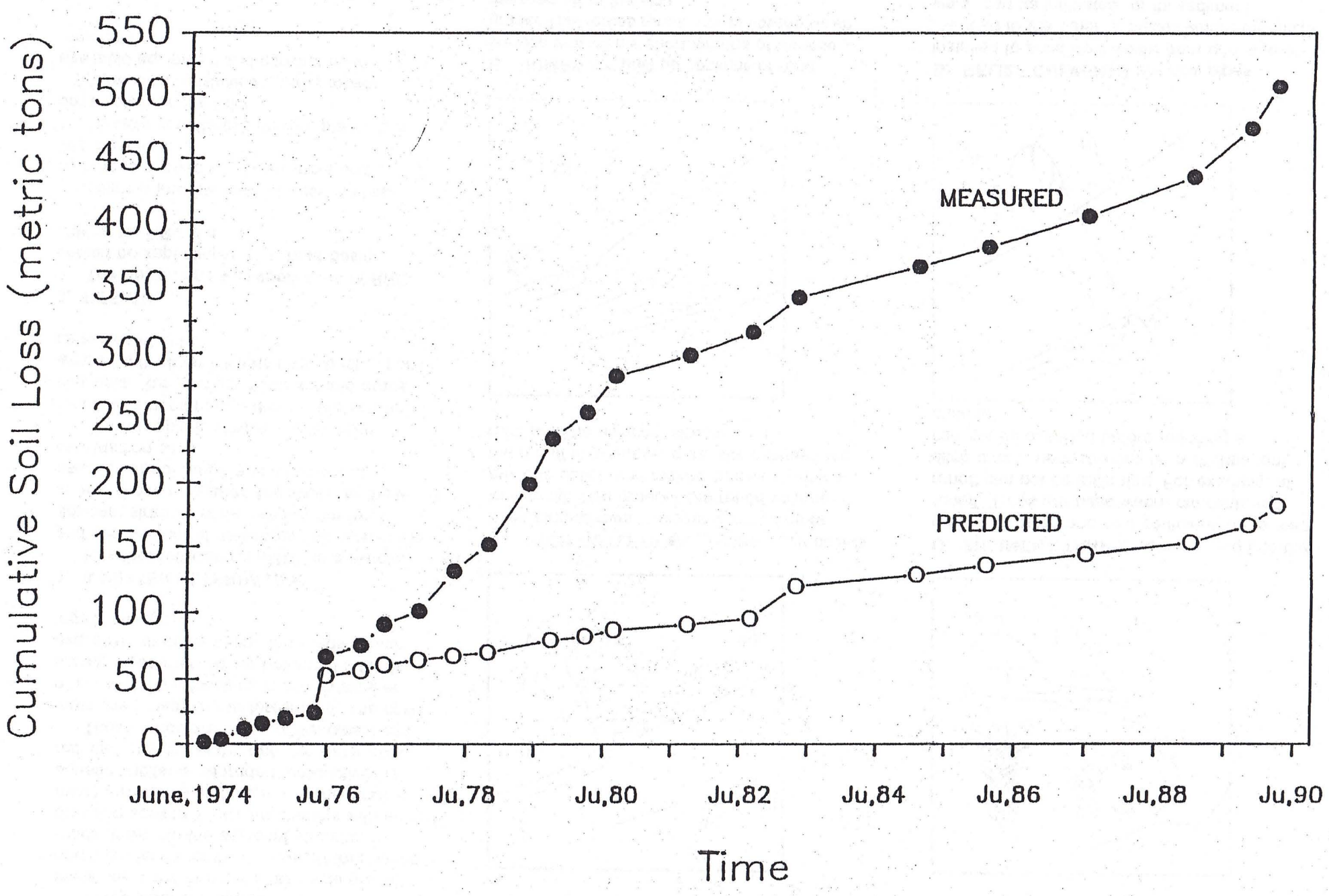


Total Watershed: 147.3 ac.
Total Road: 7.1 ac.
Stream-Crossings: 1.5 ac.

Road = 4.8% of Watershed 7
Crossings = 1.0% of Watershed 7
= 21.3% of Road Area
= 16.7% of Road Length


SOIL LOSS – t/ha
800
600
400
200
0
CUMULATIVE SOIL LOSS
SAMPLER 702
SMALL STREAM BELOW ROAD
BASED ON AREA OF ROADWAY
WHICH DRAINS DIRECTLY INTO STREAM
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
1976
1977
1978




Cumulative Soil Loss (metric tons)
550
500
450
400
350
300
250
200
150
100
50
0
MEASURED
PREDICTED
June,1974
Ju,76
Ju,78
Ju,80
Ju,82
Ju,84
Ju,86
Ju,88
Ju,90
Time

51

1. THE PROBLEM

Throughout the Appalachian Mountains there are many miles of streamside gravel and unsurfaced roads. The runoff from these roads flows into the adjacent streams, dumping sediment into the channel with each rainstorm. Once sediment is in the stream aquatic habitat is degraded, productivity is reduced, and the water unfit for many uses.

These roads are some of the oldest and most used roads in our forest land. The cost of closing and relocating, reconstructing or paving these roads is far beyond the funds available. In many cases the roads cannot legally be closed.

2. A BETTER ALTERNATIVE

Road Runoff Control (**RRC**) is a simple and effective set of measures that protect the adjacent streams while keeping the road open. These measures are similar to those used to control runoff and sediment at construction sites.

The principle is simple: control road runoff so it does not go directly into stream channels. Runoff must be forced into areas where it will either infiltrate or at least deposit its sediment load.

3. DESIGN

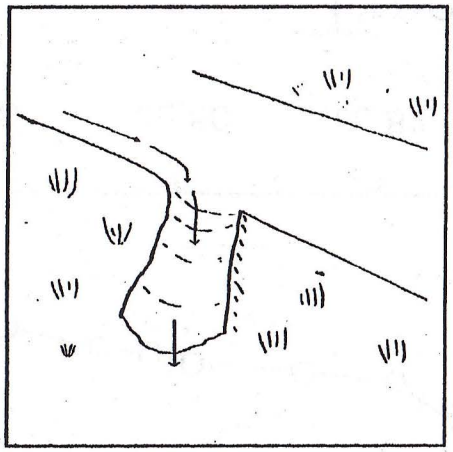
The design and field application of RRC should be kept simple. The three basic criteria for **RRC** are:

*Simple and low-tech, so only minimal training is needed for of designers and implementers;

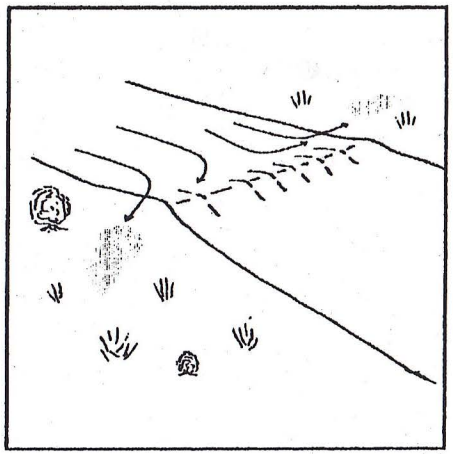
*Simple yet effective design, planning is done mostly in the field;

*Low cost construction, using locally available equipment and minimal new materials.

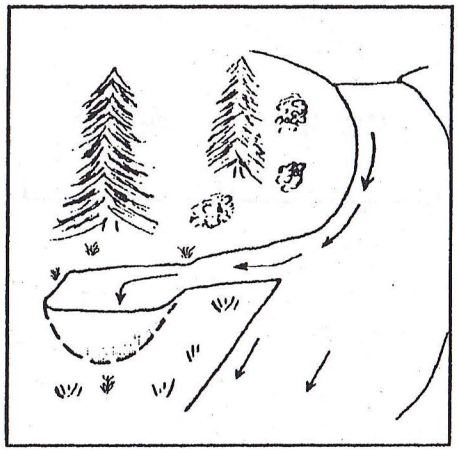
4. THE PRACTICES



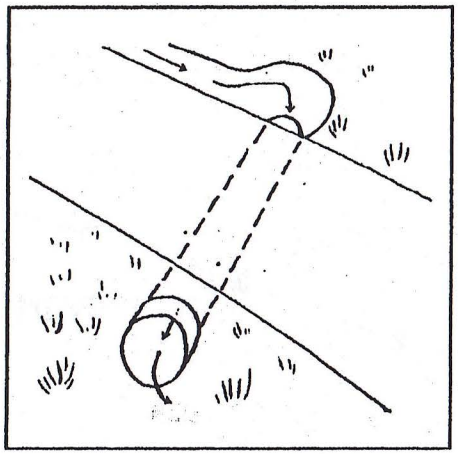
A. DITCH OUTLETS are just that, new outlets in existing ditches to disperse runoff more frequently. This reduces the runoff volume at any one outlet and makes iteasier to infiltrate the runoff in a smaller area, like between the road and the adjacent stream.



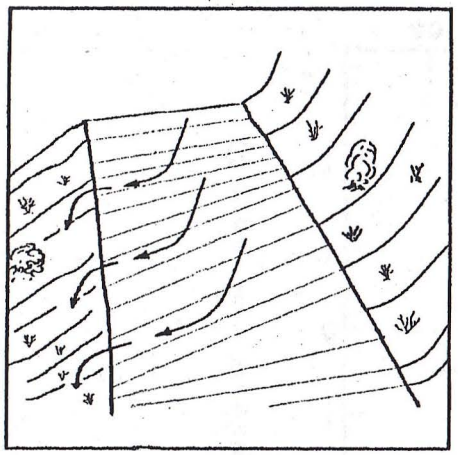
B. HUMPS are built up sections of road surface that create short lengths of reverse grade. This forces runoff that is flowing down the road off to the side.



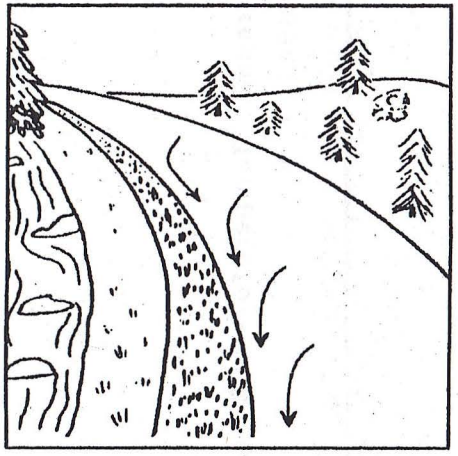
C. SEDIMENT TRAPS are holes dug into the ground to catch and hold sediment in the road runoff. Traps are used where concentrated runoff can not be infiltrated. For example, at ditch outlets near streams or in ditches that can not be outletted before reaching a channel.



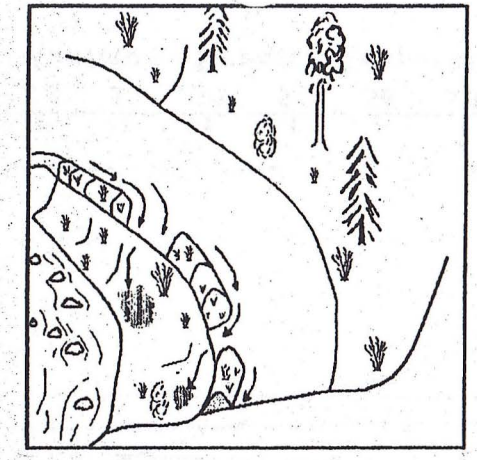
D. RELIEF CULVERTS are new pipes installed to pass ditch water from one side of the road to the other at places where the ditch water can be infiltrated or its sediment trapped.



E. OUTSLOPES are sections of road surfaces that slope to the outer road edge so runoff drains from the road surface. Outsloping serves to frequently remove water from the road in small amounts rather than allow it to gather and run the length of the road surface.



F. BERMS are low mounds or banks at the edge of the road to keep runoff on the road until the flow reaches a filter area or sediment trap site.



G. OPENINGS are outlets cut into existing berms along the road edge that hold the runoff on the road. Openings let the runoff flow from the road into infiltration areas.

5. APPLICATION

Once a section of road is selected for RRC, an overview is made to get an idea of potential sites to divert runoff and measures needed.

Starting at the lower end, walk the road identifying and marking the site for each practice. Detailed field notes should record which practice is needed and its size. This is important so the person actually doing the work will get the desired results.

When your field design is completed, you should be able to see how the entire project fits together. You should see how each practice relates to the practice above and the one below. RRC features are small and should be frequent along the road.

6. GETTING READY TO WORK

Once the field design is done, you can estimate the costs of: gravel, seed, fertilizer, and mulch, and the number of hours forhand labor and each type of equipment (backhoe, motor-grader, bulldozer).

7. DO IT IN THE DRY, DO IT IN ONE DAY

Because this work occurs in places that already put sediment into streams, it is important to schedule your work when the chance of rain is low. Each practice should be finished the same day it's started so there is low risk of construction sediment getting into the stream.

Field adjustments in size, exact site, etc. are expected once the construction starts because the project was field designed. For example you may not be able to make a sediment trap as large as planned or it may have to be moved slightly,which means adjacent practices may need adjusting to compensate.

8. IT DOES WORK

These practices have been applied to a number of streamside gravel roads in the National Forests in North Carolina. Sedimentation of adjacent streams appears to have been reduced by 75% or more. This is allowing the streams to clean previously deposited sediment out their channels.

9. MORE INFORMATION

For more detailed information on this Road Runoff Control method, please contact:

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P.O. Box 2750
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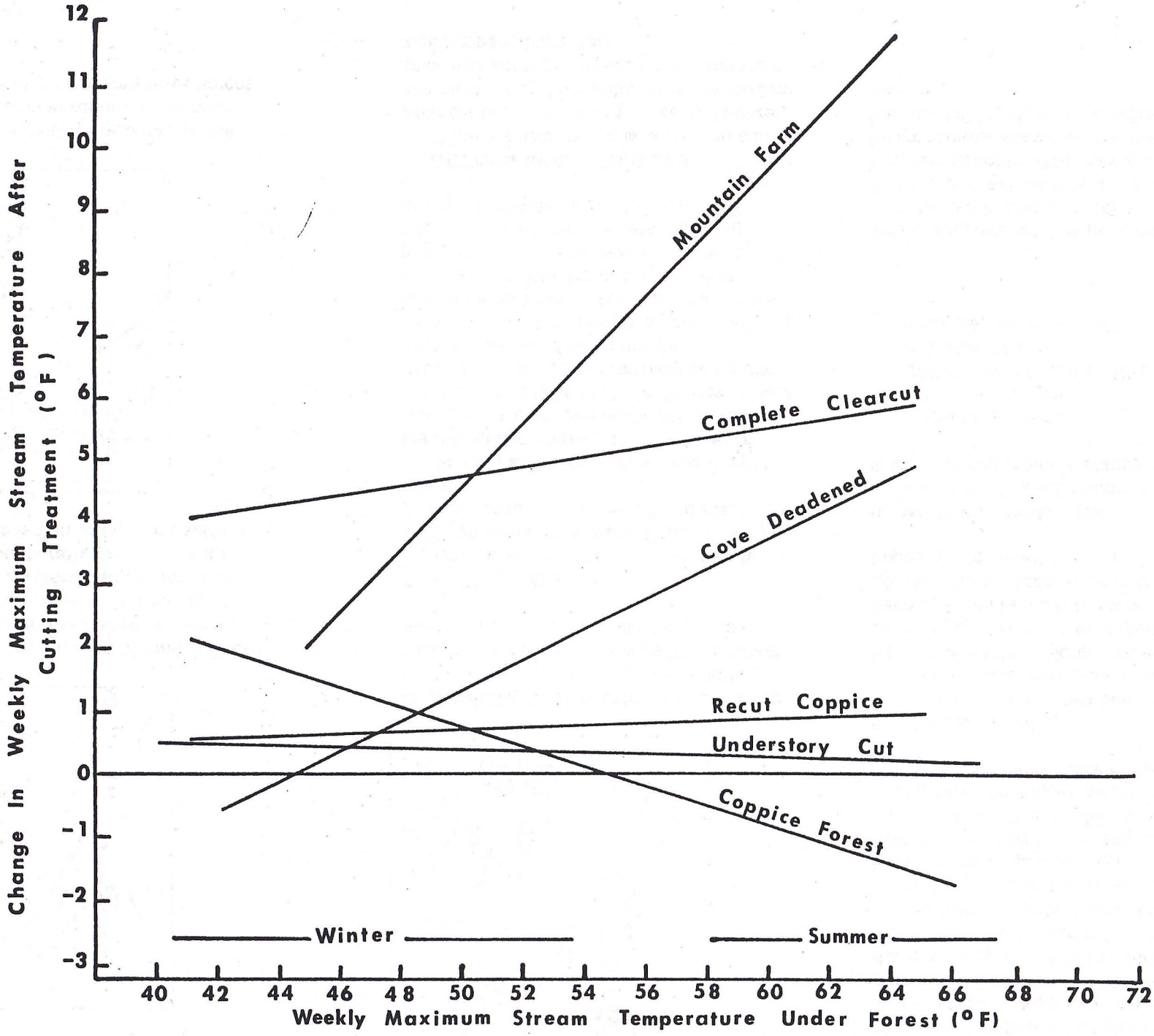
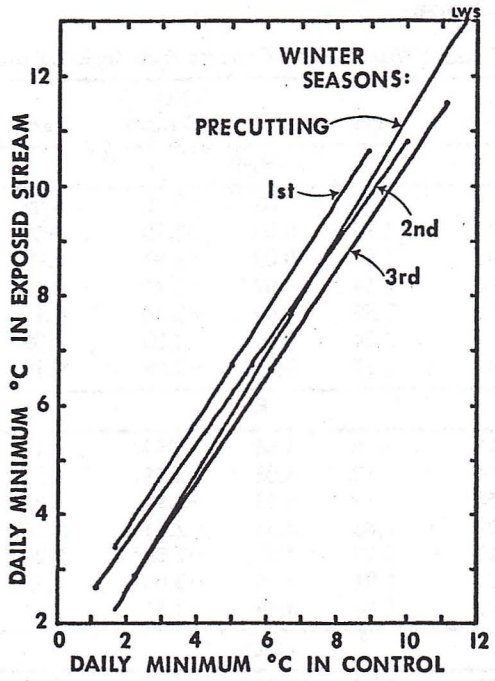
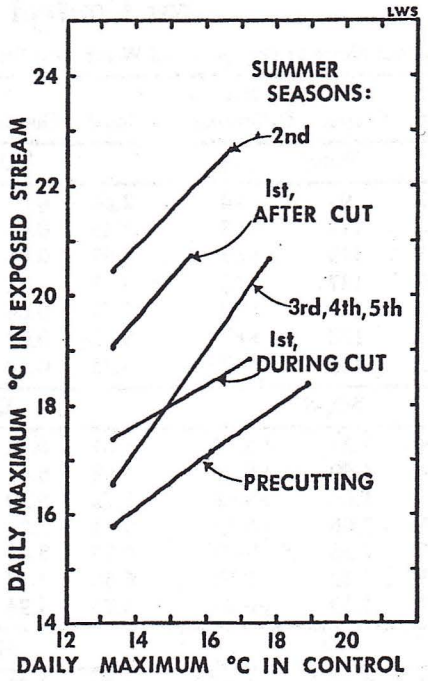
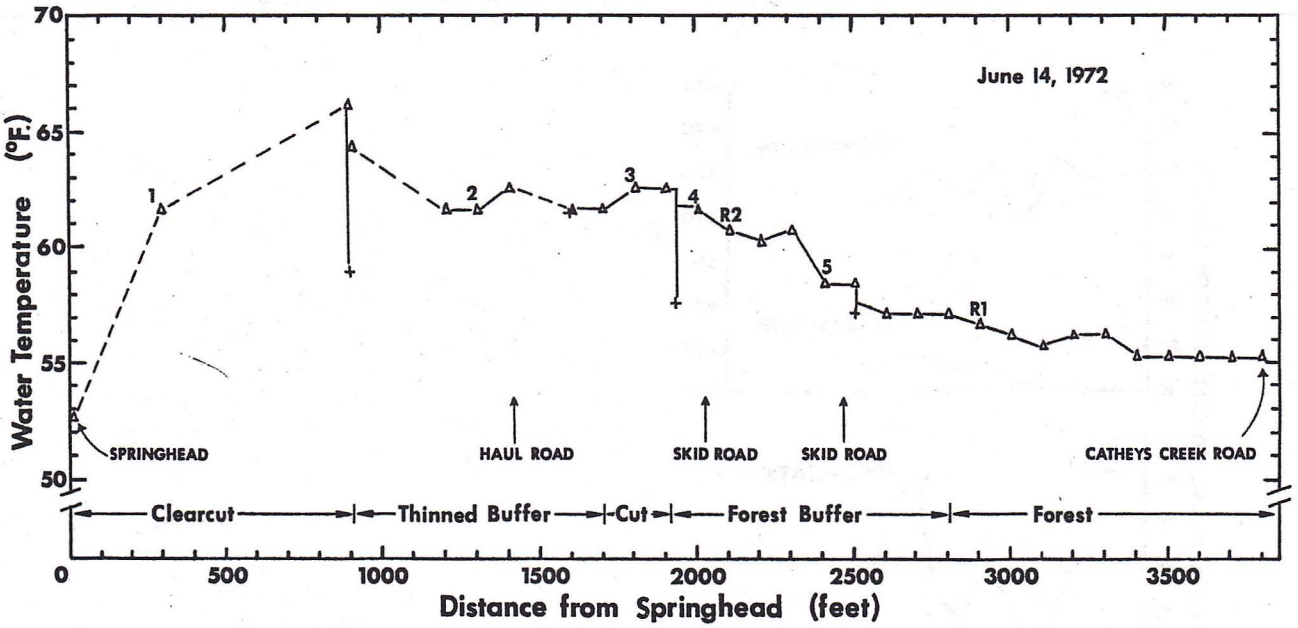

Change In Weekly Maximum Stream Temperature After Cutting Treatment (°F)
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
Mountain Farm
Complete Clearcut
Cove Deadened
Recut Coppice
Understory Cut
Coppice Forest
Winter
Summer
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
Weekly Maximum Stream Temperature Under Forest (°F)







Stream temperatures increased within the timber sale area, particularly upstream where the small creek was totally exposed. Shading and cooler ground water lowered stream temperatures within the buffer strip and full forest to levels expected for an undisturbed stream.

Characterization of Baseline Precipitation and Stream Chemistry and Nutrient Budgets for Control Watersheds

Table 4.11. Average Annual Nutrient (kg ha^{-1}) and Water (cm) Budgets for Control Watersheds at Coweeta Hydrologic Laboratory

Watershed Number	Input	Output	Net Difference	Input	Output	Net Difference	Input	Output	Net Difference	Input	Output	Net Difference
		Water			NO_3-N			NH_4-N			PO_4-P	
2	187	93	+94	2.67	0.02	+2.65	1.78	0.02	+1.76	0.08	0.02	+0.06
14	214	119	+95	3.15	0.05	+3.10	2.14	0.04	+2.10	0.09	0.02	+0.07
18	206	119	+87	2.97	0.04	+2.93	1.97	0.03	+1.94	0.09	0.02	+0.07
27	265	187	+78	4.38	0.34	+4.04	2.54	0.07	+2.47	0.12	0.03	+0.09
32	240	171	+69	3.77	0.04	+3.73	2.52	0.06	+2.46	0.11	0.02	+0.09
34	215	128	+87	3.22	0.04	+3.18	2.24	0.04	+2.20	0.09	0.02	+0.07
36	225	183	+42	3.25	0.14	+3.11	2.15	0.06	+2.09	0.10	0.02	+0.08
		SO_4-S			Cl			K			Na	
2	9.69	1.37	+8.32	5.07	6.18	−1.11	1.76	4.66	−2.90	3.17	11.43	−8.26
14	11.34	1.89	+9.45	6.98	6.44	+0.54	1.80	4.08	−2.28	4.51	8.73	−4.22
18	10.72	1.64	+9.08	5.72	6.30	−0.58	1.98	4.93	−2.95	3.56	10.31	−6.75
27	13.17	7.06	+6.11	9.44	9.21	+0.23	1.86	4.31	−2.45	5.16	9.07	−3.91
32	13.56	2.58	+10.98	8.35	8.48	−0.13	2.20	5.08	−2.88	5.24	11.18	−5.94
34	11.55	1.82	+9.73	6.60	7.37	−0.77	1.91	4.99	−3.08	4.14	11.58	−7.44
36	11.77	5.53	+6.24	6.21	9.94	−3.73	2.18	5.49	−3.31	3.89	13.79	−9.90
		Ca			Mg			SiO_2			HCO_3	
2	3.63	5.45	−1.82	0.76	3.05	−2.29	0.55	77.25	−76.70	1.27	40.44	−39.16
14	3.83	5.28	−1.45	0.88	3.25	−2.37	0.48	59.09	−58.61	–	–	–
18	4.00	7.03	−3.03	0.85	3.49	−2.64	0.62	83.69	−83.07	–	–	–
27	3.31	6.80	−3.49	1.17	3.87	−2.70	0.46	65.50	−65.04	–	–	–
32	4.25	8.25	−4.00	1.04	4.82	−3.78	–	81.43	–	–	–	–
34	3.90	8.82	−4.92	0.88	4.40	−3.52	0.44	79.81	−79.37	–	–	–
36	4.40	10.80	−6.40	0.93	4.73	−3.80	0.68	106.46	−105.78	–	–	–

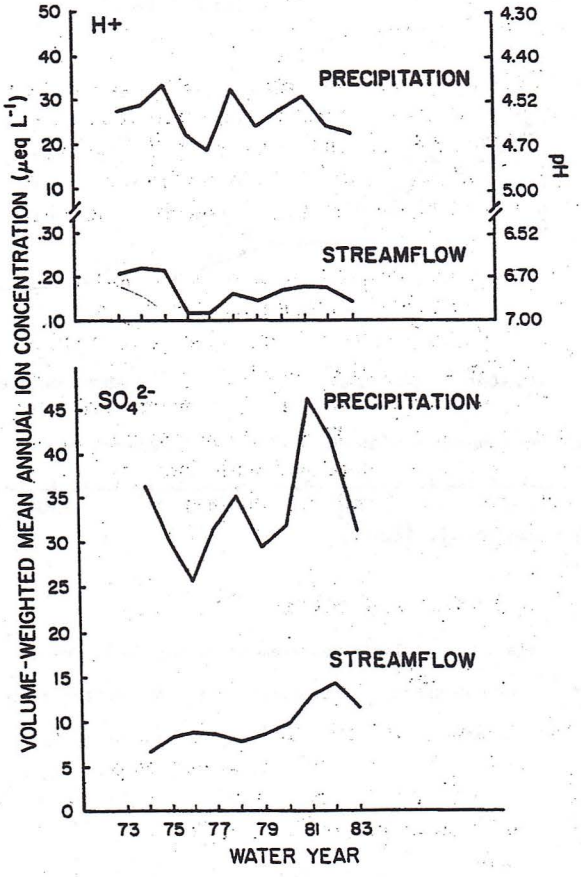


Figure 4.3. Long-term trends of volume-weighted mean annual H^+ and SO_4^{2-} concentrations in precipitation and stream water of Coweeta WS 2.

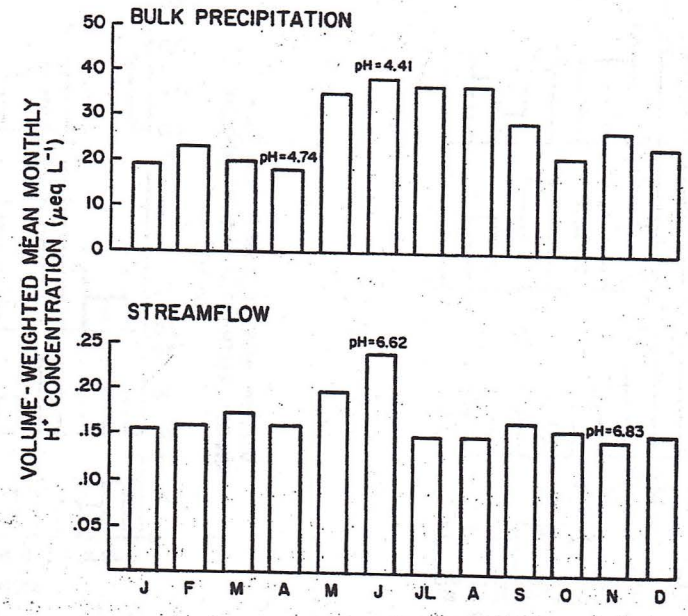


Figure 4.5. Volume-weighted mean monthly H^+ concentrations in bulk precipitation and stream water of Coweeta control WS 2 (1973–1983).

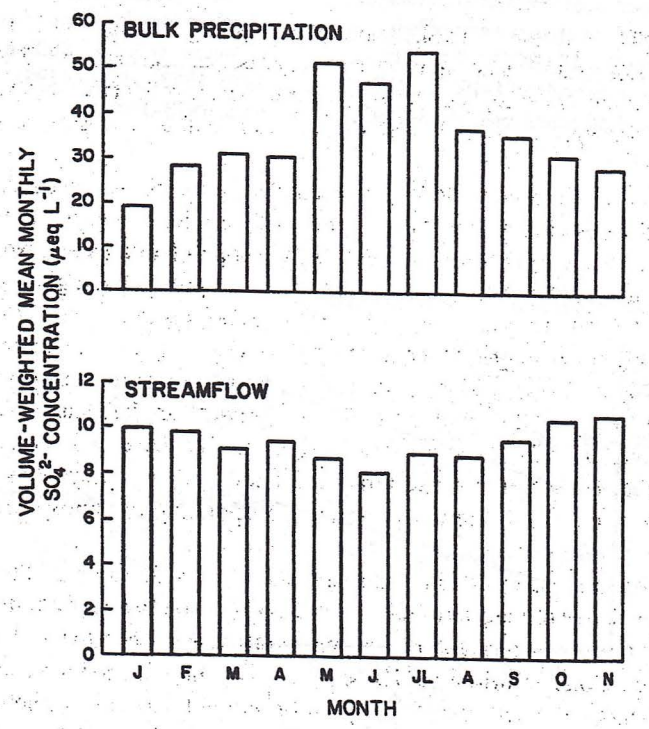


Figure 4.6. Volume-weighted mean monthly SO_4^{2-} concentrations in bulk precipitation and stream water of Coweeta control WS 2 (1974–1983).

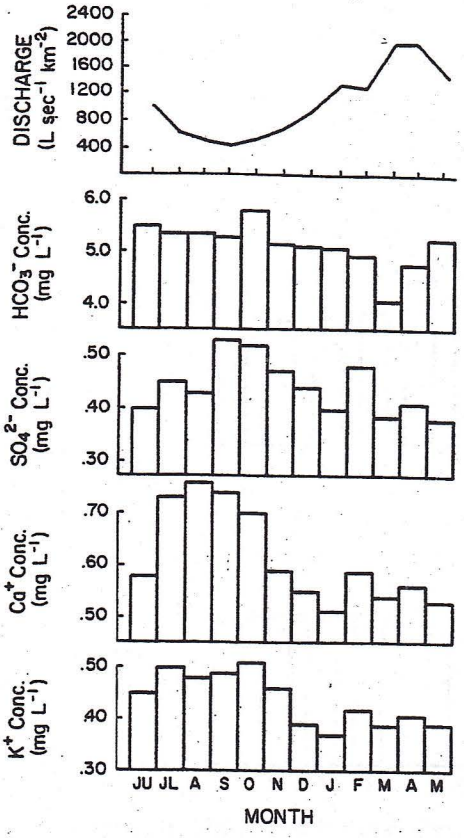


Figure 4.8. Mean monthly discharge and volume-weighted mean monthly concentrations of select ions in stream water of low elevation Coweeta WS 18 (HCO_3^- is for WS 2). Sulfate is for the period 1974–1983; HCO_3^-, 1977–1982; and all other ions, 1973–1983.

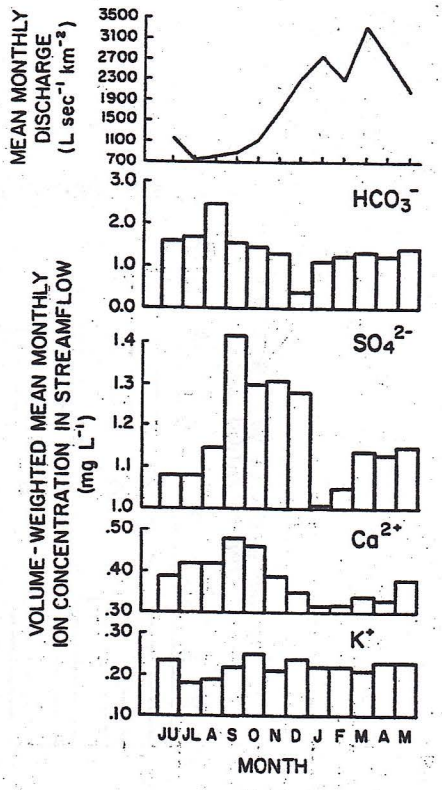


Figure 4.9. Mean monthly discharge and volume-weighted mean monthly concentrations of select ions in stream water of high-elevation Coweeta WS 36. Sulfate is for the period 1974–1983; HCO_3^-, 1981–1983; and all other ions, 1973–1983.

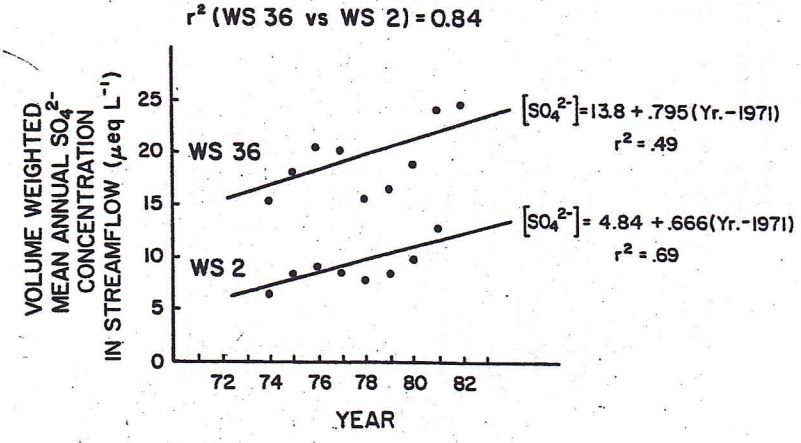


Figure 4.4. Time trends of volume-weighted mean annual SO_4^{2-} concentrations in streams draining low (WS 2) and high (WS 36) elevation Coweeta control watersheds. Analysis of covariance showed that residual variances around the regression lines are not heterogeneous ($p > 0.05$), and that regression slopes do not differ ($p > 0.250$) and have a common value of 0.731 μeq L^{-1} yr^{-1}. However, the analysis also revealed that regression elevations or intercepts do differ significantly ($p < 0.001$).

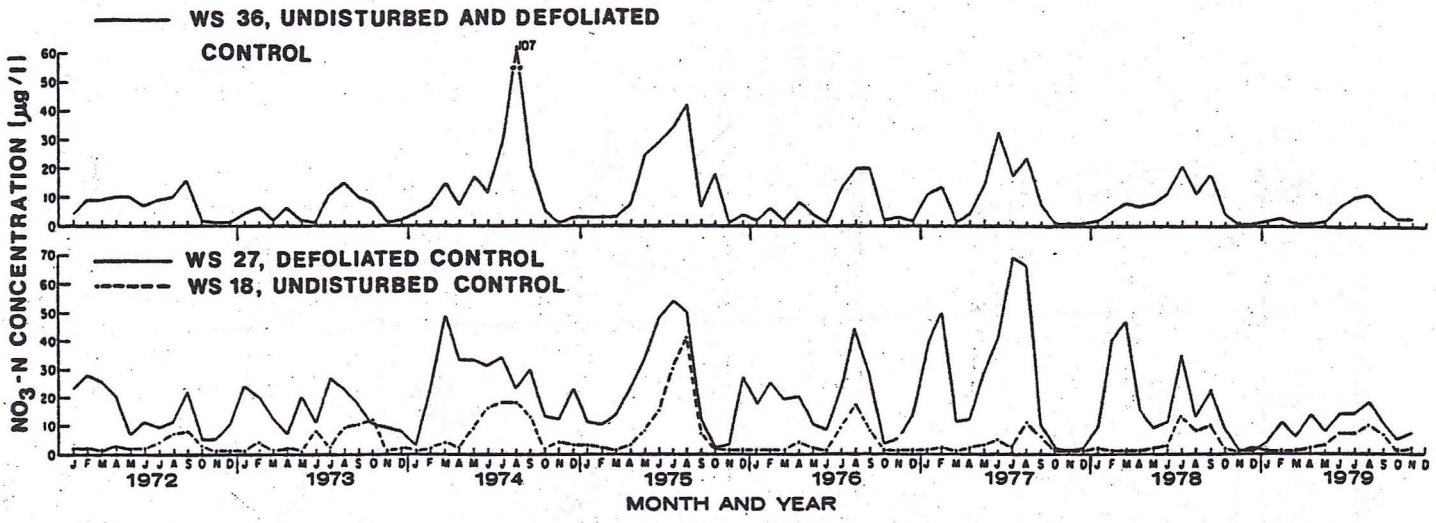
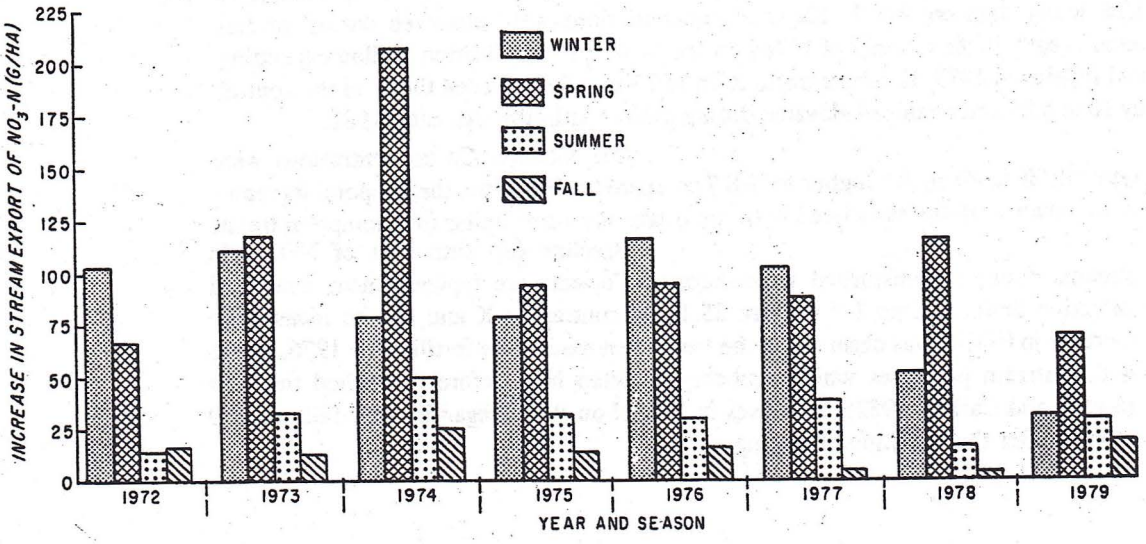


Figure 25.4. Mean monthly concentrations (flow weighted) of NO_3-N in stream water of control WS 18 compared to concentrations in streams draining two high elevation control watersheds (WS 27 and WS 36) with outbreak levels of forest defoliators.

An outbreak population of the fall cankerworm (Lepidoptera: Geometridae), a spring defoliator of hardwood forests, was first observed adjacent to and on the Coweeta Basin in 1969. Watershed 27, a 38.8 ha control catchment, was the primary site of infestation. Defoliation began in 1970 at the higher elevations (1400 m) on the catchment and progressed toward lower elevations in ensuing years. During defoliation, mean monthly concentrations of NO_3-N in stream water of WS 27 frequently rose above 40 mg L^{-1} (Figure 25.4). High concentrations were observed in late winter and also during and immediately following the time period of cankerworm feeding (late April through early June). At the peak of infestation in 1974, 33% of the total leaf mass was consumed and NO_3-N concentrations were elevated throughout the year. Subsequently, levels of defoliation were less severe, and in 1978 the population returned to endemic or nonoutbreak levels. The decline in the cankerworm population was accompanied by a return of NO_3-N concentrations toward baseline levels



Responses to Clearcutting, Logging, and Early Succession

The most precise documentation of effects of clearcutting and logging on stream chemistry conducted at Coweeta is for WS 7, where pretreatment calibrations were established.

Management of the watershed was separated into three major operations: (1) road construction and stabilization; (2) tree felling and logging; and (3) site preparation.

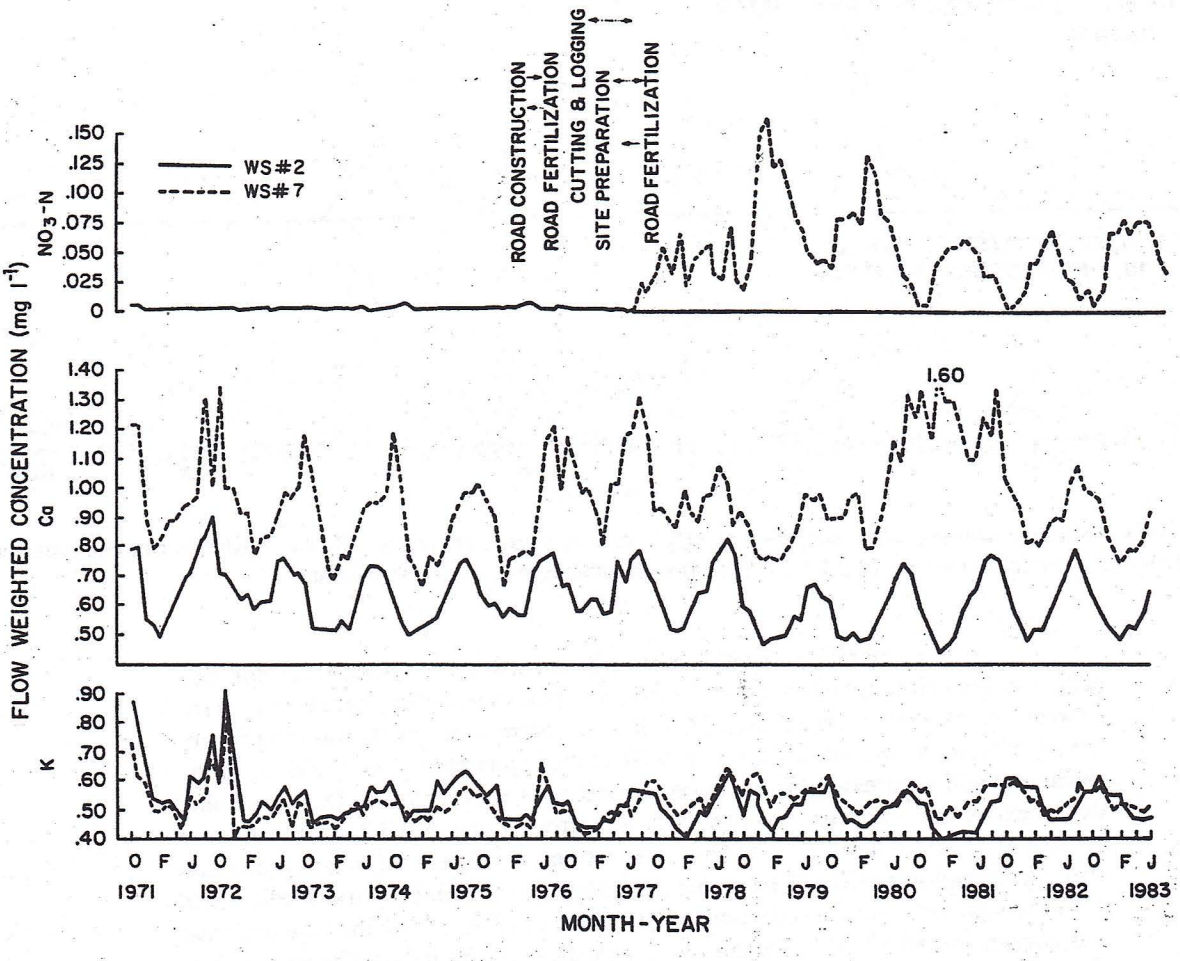

ROAD CONSTRUCTION
ROAD FERTILIZATION
CUTTING & LOGGING
SITE PREPARATION
ROAD FERTILIZATION
WS#2
WS#7
NO3-N
Ca
K
1.60
FLOW WEIGHTED CONCENTRATION (mg l-1)
O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983
MONTH-YEAR

Figure 25.1. Mean monthly concentrations (flow weighted) of K, Ca, and NO_3-N in streamwater of WS 7 during calibration, road construction, clearcutting and logging, site preparation, and post-harvest recovery periods. Data are based on samples collected weekly.

Throughout the five year calibration period, mean monthly K concentrations on WS 7 were typically 10 to 15% lower than on WS 2. Elevated concentrations were observed during several months early in the summer of 1976 in response to road fertilization. Following cutting and logging in 1977, K concentrations on WS 7 usually exceeded those on the control by 10 to 40% and remained elevated during most months through early 1981.

Baseline monthly Ca concentrations were typically 30 to 40 mg L^{-1} higher on WS 7 compared to WS 2, but the temporal increases in Ca concentrations associated with the treatment were similar to K temporal trends

Baseline concentrations of NO_3-N in streams draining undisturbed watersheds at Coweeta are typically near analytical detection limits of 2 µg L^{-1} (Figure 25.1). In contrast to K and Ca, no measurable increase in NO_3-N was observed at the weir when roads were fertilized in 1976, due to within stream processes which probably depleted NO_3 before it reached the weir (Swank and Caskey, 1982). Increases in NO_3-N on WS 7 began in early fall, about 9 months after the initiation of cutting.

: 25.2. Average Annual Flow Weighted Concentrations[a] (mg/L) of Dissolved Inorganic Constituents and Flow (cm) for Streams Draining Treated ersheds at Coweeta

Watershed Number	Vegetation Type	Flow	NO_3-N	NH_4-N	PO_4	Cl	K	Na	Ca	Mg	SO_4	SiO_2
1	White pine	67	0.02	0.003	0.008	0.68	0.52	1.06	0.65	0.36	0.41	5.42
6	Grass-to-forest succession	100	0.67	0.005	0.007	1.04	0.55	1.00	0.99	0.60	0.44	6.59
7	Coppice regrowth	118	0.04	0.004	0.007	0.65	0.52	0.95	0.90	0.38	0.52	7.67
8	Combination of control and treated	132	0.01	0.003	0.005	0.52	0.38	0.78	0.81	0.32	0.65	6.65
13	Coppice regrowth	122	0.04	0.003	0.004	0.49	0.38	0.64	0.45	0.26	0.39	5.73
17	White pine	80	0.13	0.004	0.006	0.53	0.39	0.79	0.51	0.23	0.48	6.72
28	Combination coppice regrowth, even-aged poplar cove, and mature hardwoods	196	0.13	0.004	0.005	0.51	0.43	0.85	0.96	0.44	0.47	NA
37	Coppice regrowth	201	0.18	0.004	0.004	0.47	0.38	0.64	0.73	0.31	1.14	4.64
40	Uneven-aged mixed hardwoods	147	0.005	0.004	0.008	0.61	0.54	1.12	1.04	0.40	0.45	NA

[a] Period of record (June–May water year): For WS 6, 7, 8 and 17 all ions for the period 1973–1983 except for SO_4, 1974–1983 and SiO_2, 1975–1983. For WS 1 and 13 all ions for the periods of 1973–74 and 1982–83 except no SO_4 data in 1973 and SiO_2 data in 1973–74. For WS 28 all ions for the period 1973–74 except no SO_4 in 1973. For WS 37 all ions in 1973–74 and 1983 except no SO_4 data for 1973 and SiO_2 data in 1973–74. WS 40, data available only for 1973.

Table 25.4. Average Annual Nutrient Budgets (kg/ha) for Treated Watersheds at Coweeta Hydrologic Laboratory

Watershed Number	Input	Output	Net Difference	Input	Output	Net Difference	Input	Output	Net Difference	Input	Output	Net Difference
		Water (cm)			NO_3-N			NH_4-N			PO_4-P	
1	189	67	122	2.83	0.16	+2.67	1.98	0.02	+1.96	0.25	0.05	+0.20
6	195	100	95	2.82	6.68	−3.86	1.89	0.05	+1.84	0.26	0.07	+0.19
7	188	118	70	2.69	0.42	+2.27	1.77	0.04	+1.73	0.25	0.08	+0.17
8	212	132	80	3.04	0.19	+2.85	2.02	0.04	+1.98	0.28	0.06	+0.22
13	218	122	96	3.19	0.50	+2.69	2.17	0.03	+2.14	0.30	0.05	+0.25
17	211	80	131	3.03	1.00	+2.03	2.01	0.03	+1.98	0.29	0.05	+0.24
28	277	196	81	4.10	2.50	+1.60	3.06	0.08	+2.98	0.43	0.09	+0.34
37	244	201	43	3.66	3.66	0.00	2.44	0.09	+2.35	0.35	0.09	+0.26
40	244	147	97	3.58	0.08	+3.50	2.69	0.05	+2.64	0.37	0.11	+0.26
		Cl			K			SO_4			Na	
1	5.70	4.54	+1.16	1.66	3.44	−1.78	30.32	2.71	+27.61	3.59	7.08	−3.49
6	5.42	10.38	−4.96	1.86	5.53	−3.67	30.58	4.33	+26.25	3.37	10.06	−6.69
7	5.10	7.64	−2.54	1.78	6.11	−4.33	29.20	6.07	+23.13	3.19	11.18	−7.99
8	5.81	6.87	−1.06	2.03	4.98	−2.95	33.10	8.44	+24.66	3.62	10.32	−6.70
13	6.76	5.98	+0.78	1.84	4.58	−2.74	32.25	4.52	+27.73	4.42	7.86	−3.44
17	5.85	4.24	+1.61	2.02	3.11	−1.09	32.83	3.58	+29.25	3.64	6.33	−2.69
28	10.43	9.98	+0.45	2.87	8.41	−5.54	48.01	8.94	+39.07	7.34	16.67	−9.33
37	7.98	9.40	−1.42	2.20	7.62	−5.42	38.78	21.72	+17.06	5.19	12.77	−7.58
40	8.84	8.93	−0.09	2.41	7.90	−5.49	–	–	–	6.21	16.36	−10.15
		Ca			Mg			SiO_2				
1	3.43	4.34	−0.91	0.77	2.41	−1.64	0.38	36.03	−35.65			
6	3.80	9.93	−6.31	0.78	5.99	−5.21	0.58	62.54	−61.96			
7	3.66	10.60	−6.94	0.76	4.50	−3.74	0.56	87.57	−87.01			
8	4.13	10.63	−6.50	0.87	4.25	−3.38	0.62	83.98	−83.36			
13	3.91	5.45	−1.54	0.87	3.22	−2.35	0.46	58.25	−57.79			
17	4.10	4.04	+0.06	0.87	1.86	−0.99	0.63	49.79	−49.16			
28	5.45	18.92	−13.47	1.17	8.66	−7.49	–	–	–			
37	4.56	14.59	−10.03	1.03	6.18	−5.15	0.57	86.47	−85.90			
40	4.74	15.23	−10.49	1.00	5.86	−4.86	–	–	–			

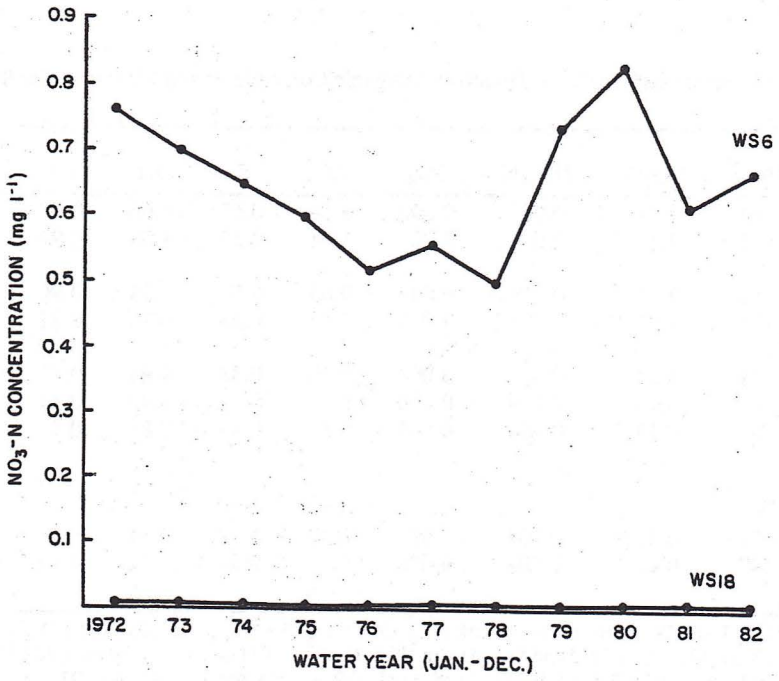


Figure 25.6. Mean annual concentrations (flow weighted) of NO_3-N in streams draining control WS 18 and WS 6 during the period of grass-to-forest succession.

1. Over the period of observation beginning in 1972, none of the disturbances produced nutrient concentrations that would have an adverse impact on water quality for municipalities or downstream fisheries.
2. Compared to other forested regions of the United States, increases in nutrient concentrations of streams are small, even for the most drastic vegetation disturbances.
3. Nitrate-N is a sensitive indicator of forest disturbance and although concentrations are quite low (<0.2 mg L^{-1}), elevated levels in streams draining clearcuts appear to persist for at least 20 years after cutting.
4. Comparisons of annual nutrient input and output budgets for control versus disturbed watersheds illustrate the importance of evapotranspiration (*Et*) processes in regulating biogeochemical cycles. Hardwood to white pine conversion increased *Et*, reduced annual stream discharge, and consequently reduced the export of some dissolved nutrients. Conversely, clearcutting reduced *Et*, increased water flux, and increased nutrient export.
5. Budget data, combined with process research, also demonstrate the importance of biological processes in nutrient retention and loss from forest ecosystems. Decomposition, net primary production, and uptake and storage of nutrients in successional vegetation are important factors that regulate the magnitude and timing of nutrient exports.
6. Outbreak infestations of two different insects provide evidence for insect regulation of nutrient recycling and losses at an ecosystem level as revealed by changes in stream chemistry.

Fire as a silvicultural tool to improve southern Appalachian pine/hardwood stands

Problem: Restore degraded pine/hardwood stands

- Pine/hardwood ecosystem:
  - dry to xeric ridges and steep slopes
  - Pinus rigida with mixture of hardwoods, including Quercus coccinea, Q. prinus, Acer rubrum with Kalmia latifolia in the understory.
  - a unique vegetation type in the Southern Appalachians

Benefits of Fire

- Provides seedbed conditions for pine germination
- Reduces Kalmia latifolia to allow pine seedling establishment
- Encourages oaks to sprout
- Promotes forage production

Hypotheses

- High intensity burn along the ridge would simulate a wildfire
- Moderate intensity burn at mid-slope would reduce K. latifolia and promote forage production and oak regeneration
- Low intensity, surface burn along near-riparian low-slope would promote regeneration of herb-layer species

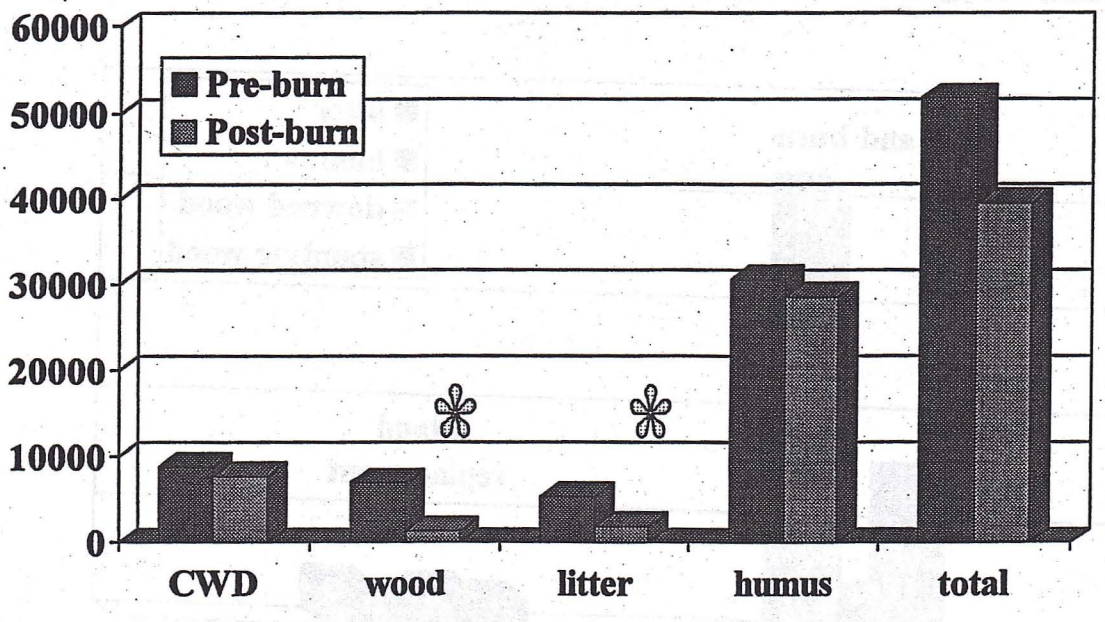
Fire characteristics

- Intensity: peak flame temperatures ranged from 80 to >800 °C, resulting in a mosaic of fire intensities. Fuel consumption on the ridge (42% for litter, 4% for humus, and 25% for small wood).
- Severity: heat penetration to forest floor varied across slope positions (24-27 mm on ridge; 17-18 mm at mid-slope; <0.6 mm at low-slope)

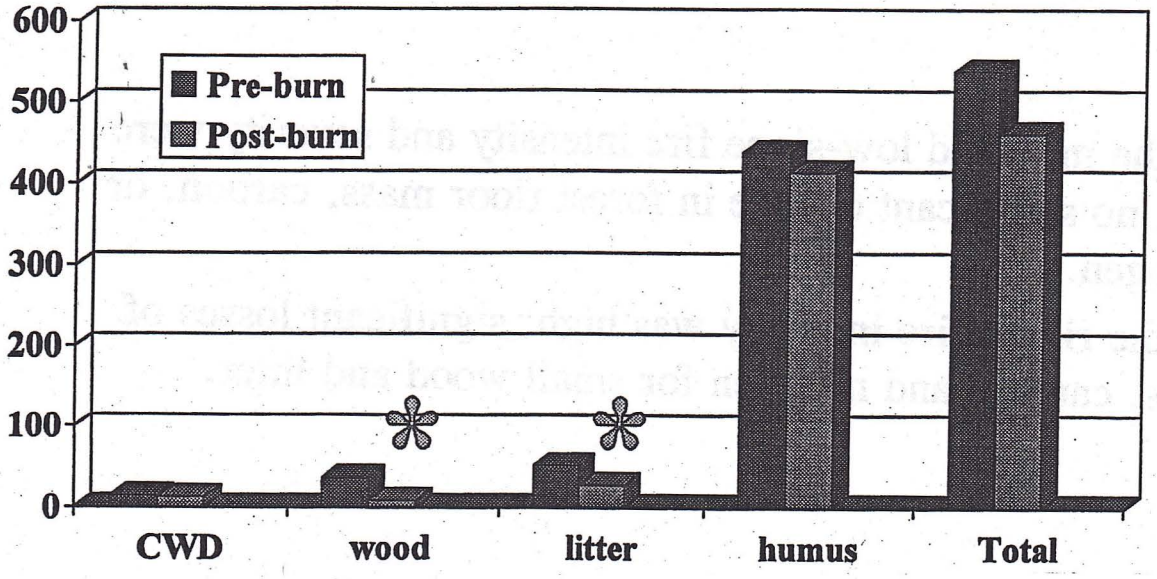
Forest floor mass, carbon, and nitrogen

- On the mid- and low-slope fire intensity and severity were low; no significant change in forest floor mass, carbon, or nitrogen.
- On the ridge, fire intensity was high; significant losses of mass, carbon, and nitrogen for small wood and litter.

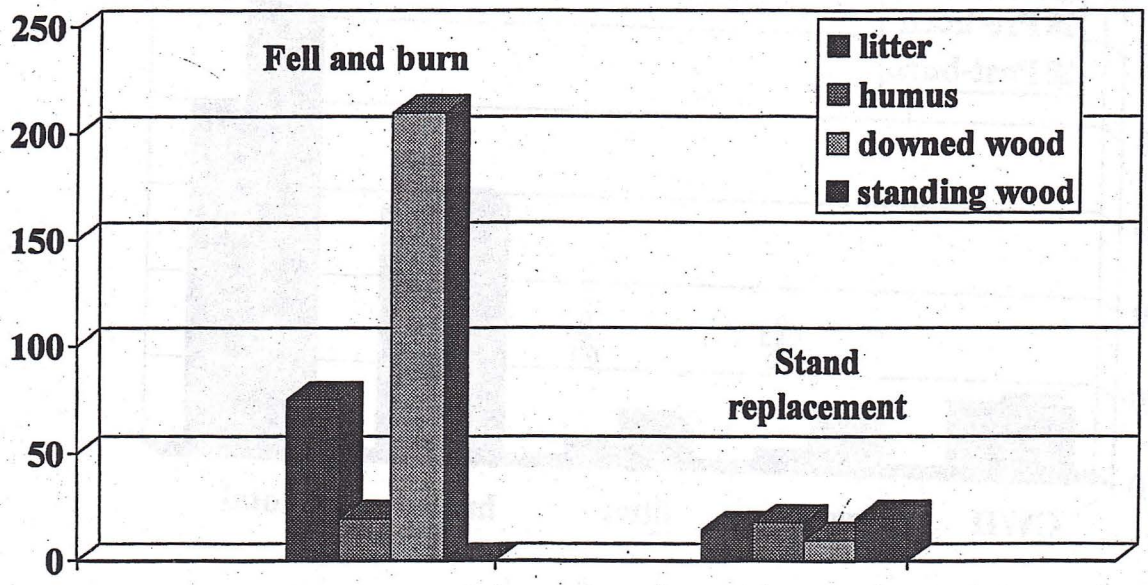
Forest floor mass (kg/ha)



Forest floor nitrogen (kg/ha)



Nitrogen loss (kg/ha)



Soil and stream chemistry

- Burning treatment had little or no effect on soil chemisty.
- Lack of stream NO_3^--N or NH_4^+-N response to burning was not unexpected since fire severity was low near the stream and no overland flow occurred.

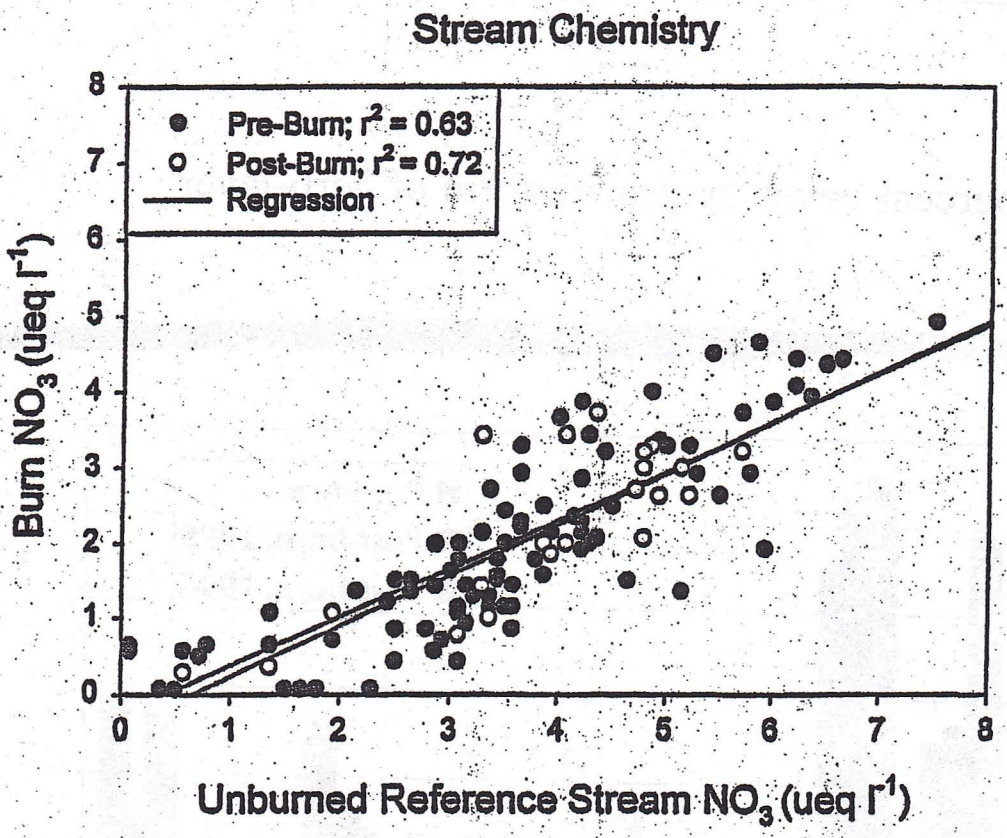
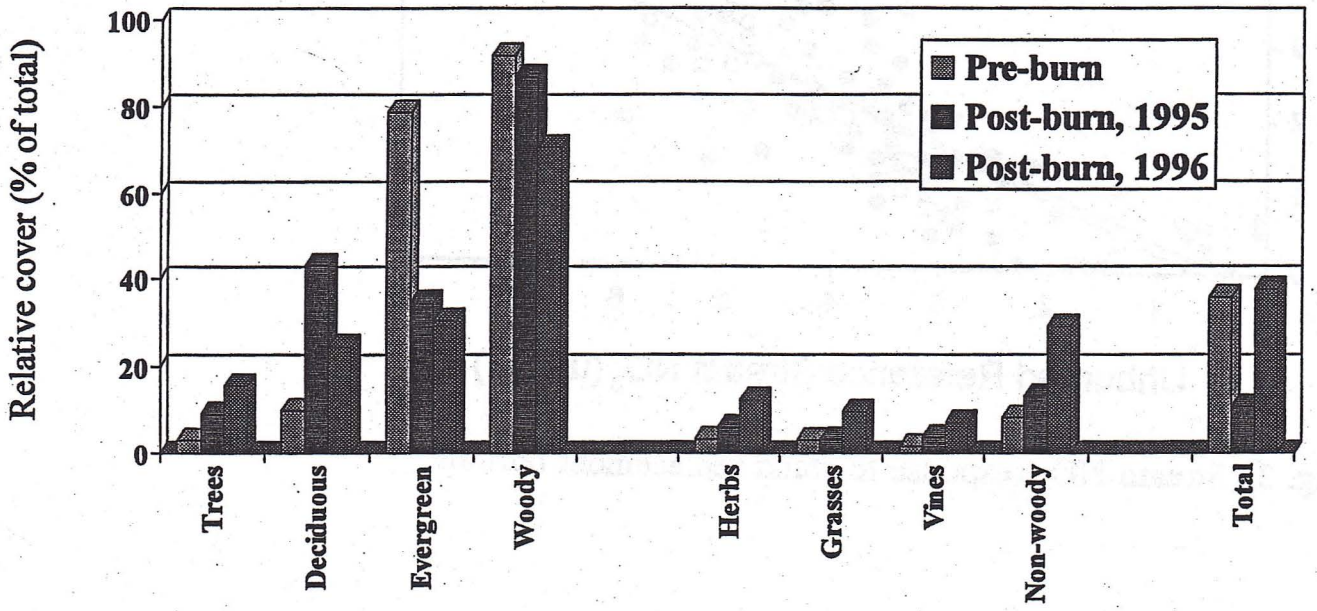


Fig. 3. Stream NO_3 response to stand replacement burning.

Vegetation dynamics

- Overstory mortality was highest on the ridge (31%).
- Fire had varying effects on species richness and diversity across the hillslope gradient.
- The first summer after burning, P. rigida germinated prolifically. By 1996, most of these germinants had died and seedling numbers were less than pre-burn.
- K. latifolia was substantially reduced, allowing for an increase in other genera such as Vaccinium, Gaylussacia, Rubus, and Robinia.

Ridge: relative percent cover by growth form of herb-layer vegetation



Small mammals and insects

- There was little or no change in small mammals or herpetofauna after burning.
- Groups of microarthropods responded differently to the burning treatment.
  - Prostigmata (small and delicate forms) <50% of preburn numbers)
  - Mesostigmata (robust predators)- little reduction
  - Collembolas (opportunistic species) - increased
  - Oribatid mites numerous and species rich (110) - numbers were reduced, 22 species lost

Management Implications

- Creation of mosaic of effects
  - resulting in mix of species comparable to wildfire derived communities
- Lower N losses than other fire treatments, such as fell and burn
- Lower cost to implement than fell and burn
- Pine regeneration ? Oak regeneration?
- Increased forage production (soft-mass, berries)
- Difficult to apply prescription
- Limited opportunity for additional management (e.g., product removal and planting)

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